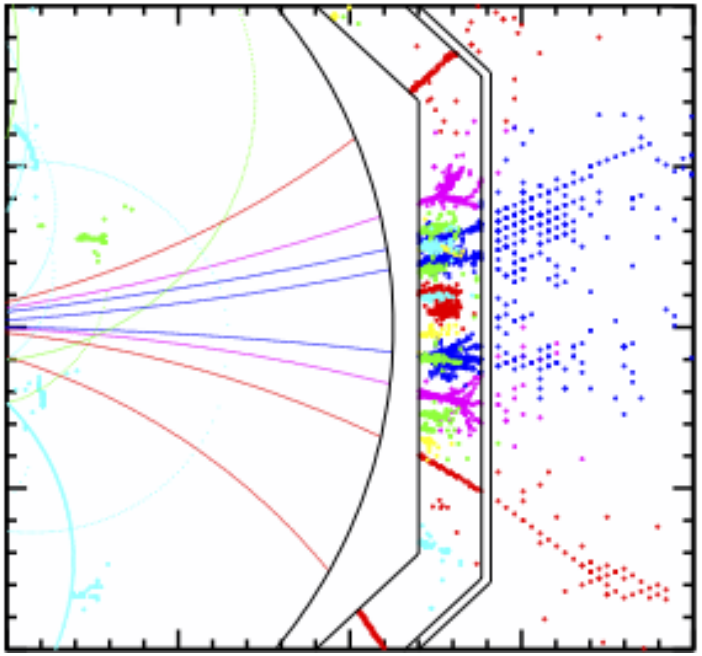
Software Compensation for AHCAL optimisation



Huong Lan Tran

FLC Long Talk - November 30, 2015

HELMHOLTZ ASSOCIATION

CALICE

DESY

Outlines

- Discussion about overall size of ILD and cost
  - HCAL cell sizes, HCAL thickness, different granularities @ different depth
- Intensive work on-going to re-optimise HCAL
  - New version of Pandora shows better resolution
    - Impact of energy reconstruction

In this talk: Software compensation for AHCAL optimisation

- Why compensation?
- Methods to achieve compensation
- Software compensation (SC)
  - Idea & Definitions
  - Implementation in Particle Flow Algorithm
  - Towards a common SC technique for different types of HCAL

Why Compensation?

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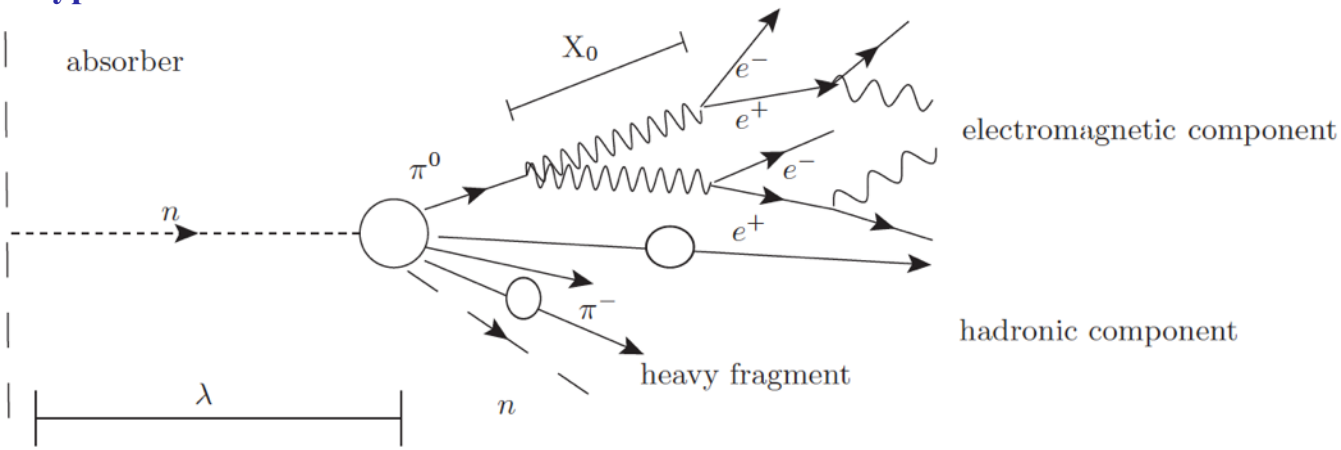
DESY

Why Compensation?

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

Typical hadronic shower



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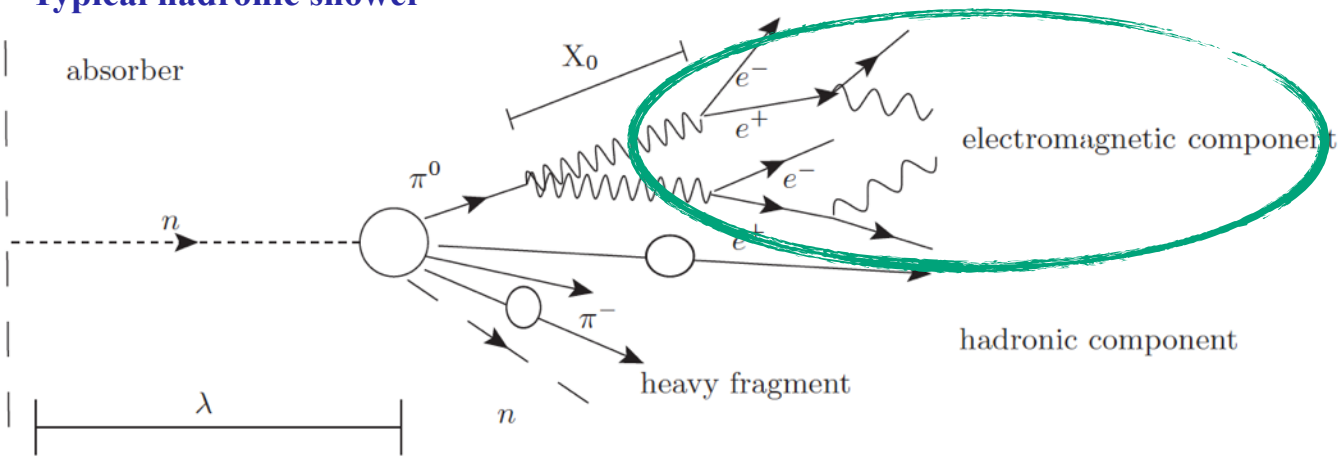

Detected via energy loss of electrons and photons in active medium

Why Compensation?

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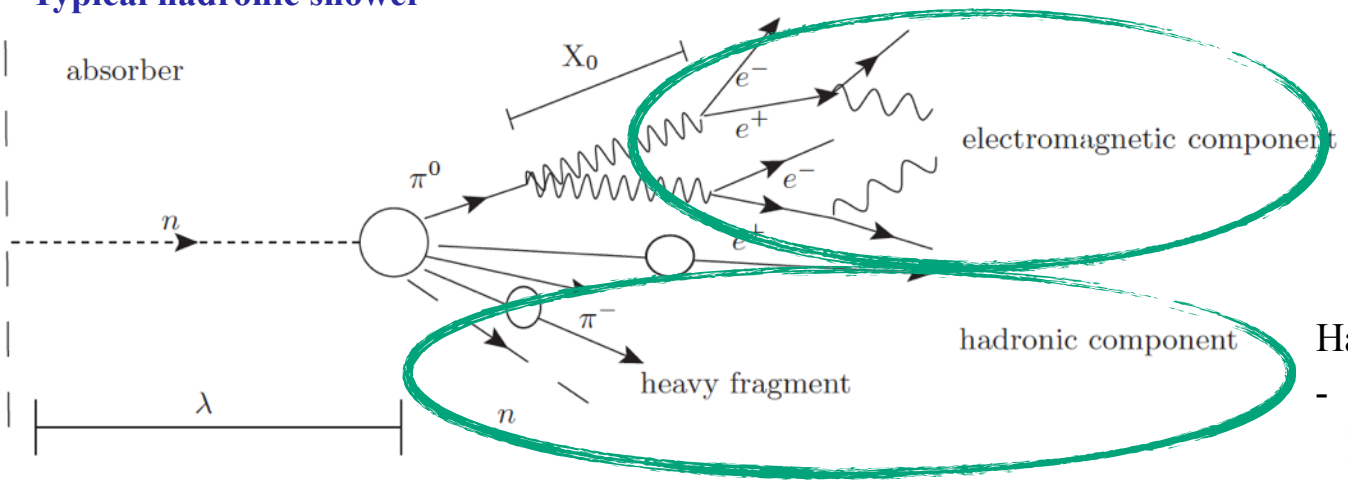
Typical hadronic shower



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

Why Compensation?

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

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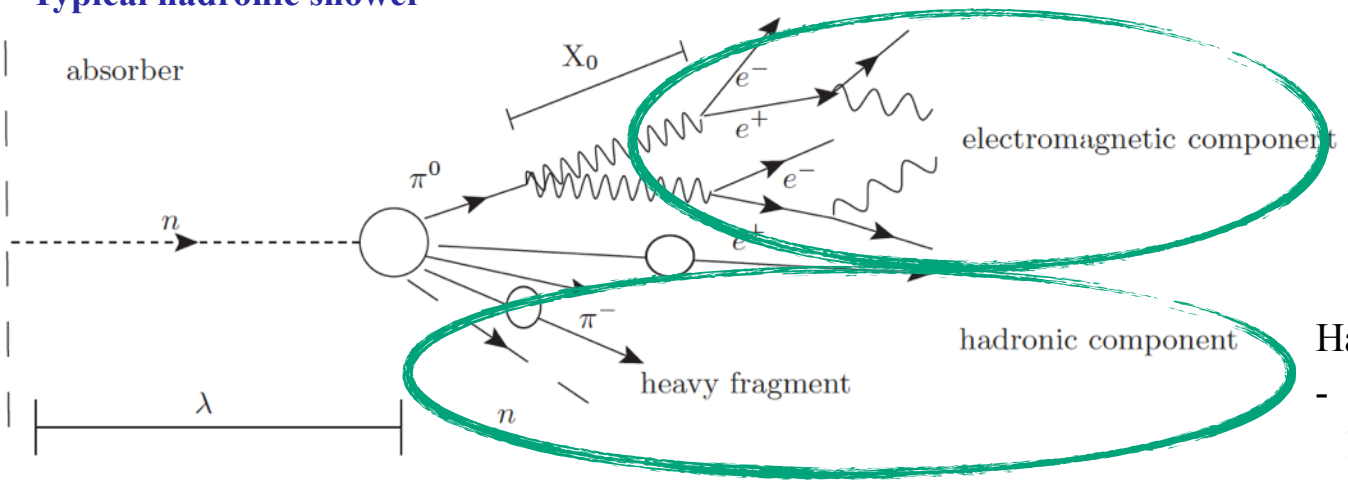


Detected via energy loss of electrons and photons in active medium

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

➪ Smaller calorimeter response for this part

➢ **Consequences:**

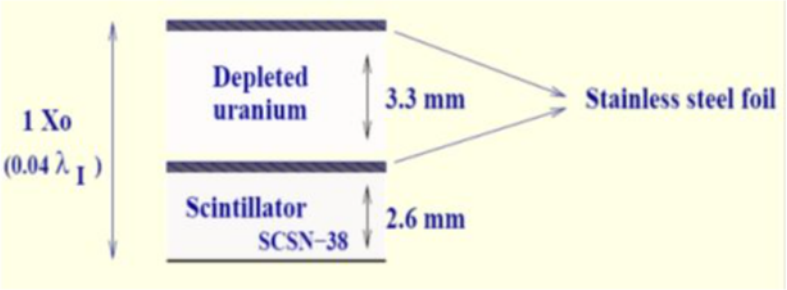
- Higher detector response for electromagnetic compared to hadronic showers $\frac{e}{h} > 1$
- Non-linearity for hadronic calorimeter response
- Degradation of energy resolution

Methods to achieve Compensation

- Reducing electromagnetic response
- Increasing hadronic response

Methods to achieve Compensation

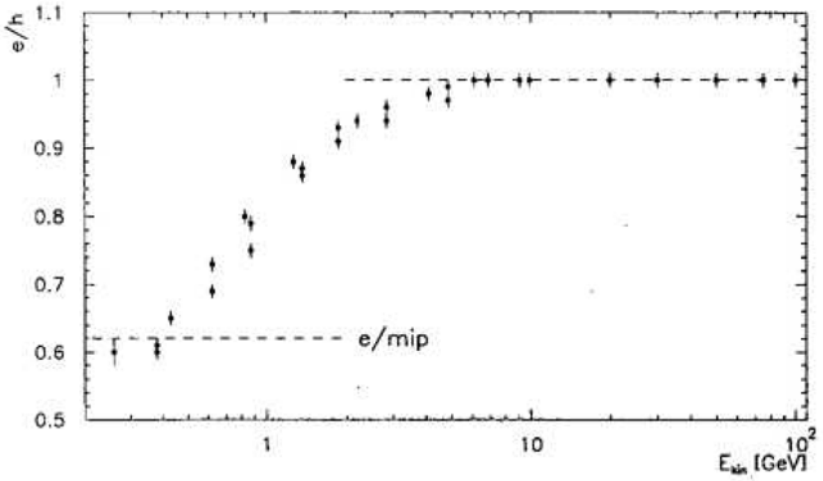
- Reducing electromagnetic response
- Increasing hadronic response



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
- …



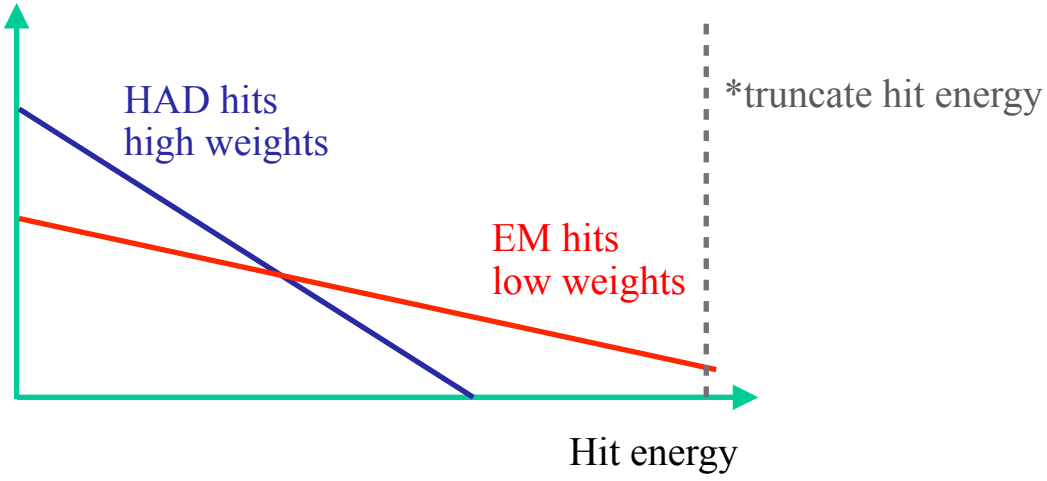
ZEUS e/h response ratio
=1 within 1% for E > 3GeV

Methods to achieve Compensation

- Reducing electromagnetic response
- Increasing hadronic response
- "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

Idea & Implementation

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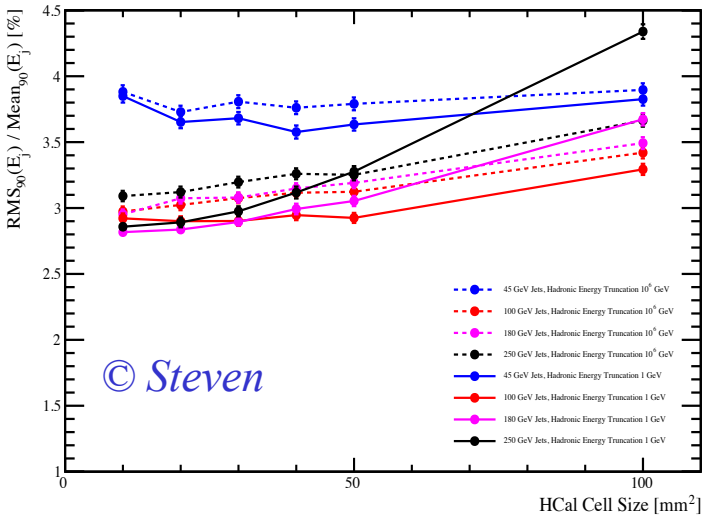
Software Compensation in AHCAL optimisation

- 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

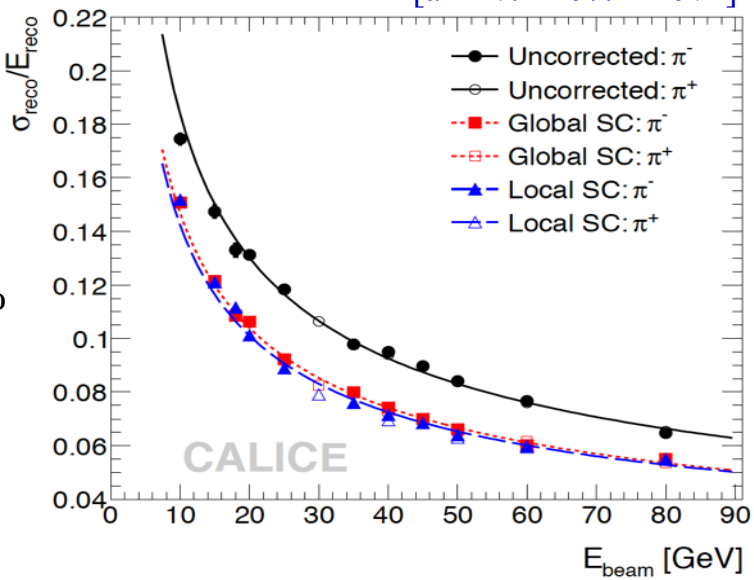


➢ Cell energy truncation mimics software compensation

➢ 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

- ***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:

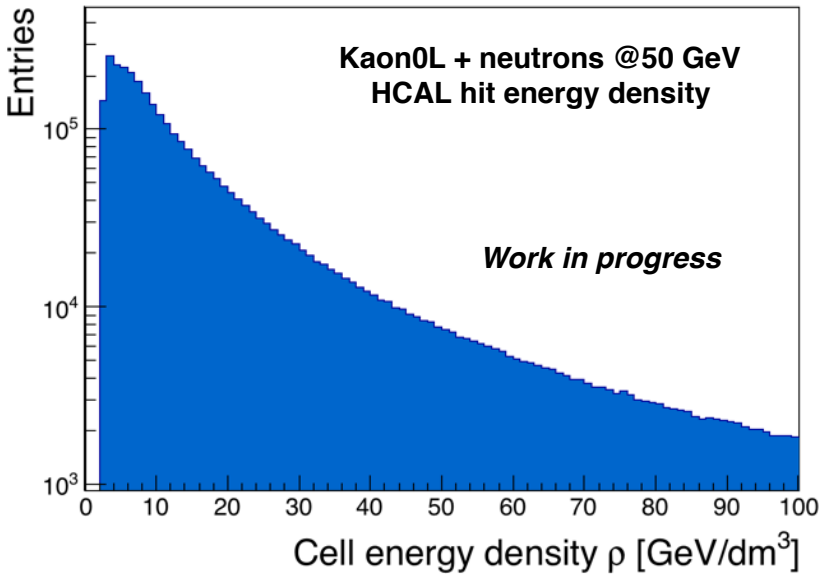
$$E_{SC} = \sum_{hits} E_{ECAL} + \sum_{hits} (E_{HCAL}.\omega(\rho))$$

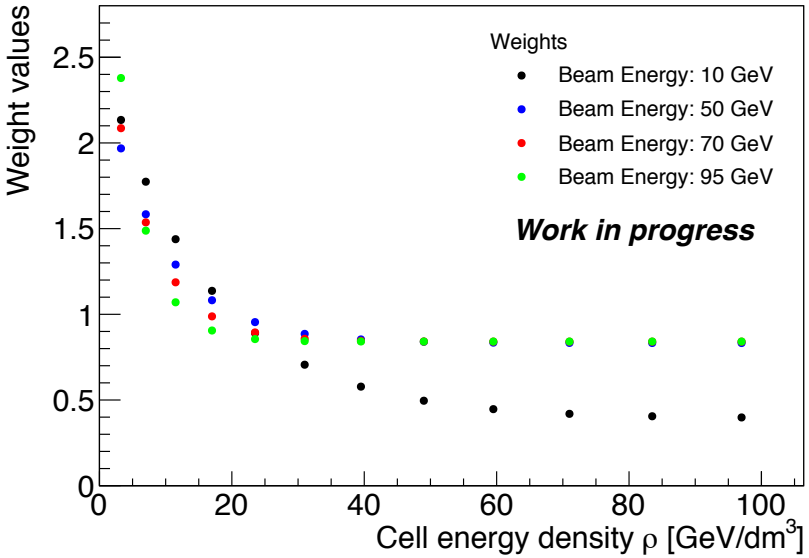
- Weights determined through minimising a χ^2 function:

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

- 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

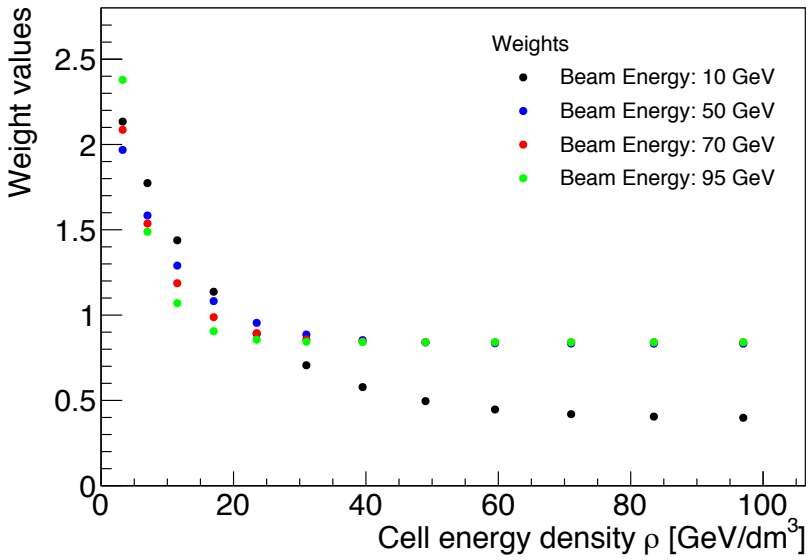
Weight determination:

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

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

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

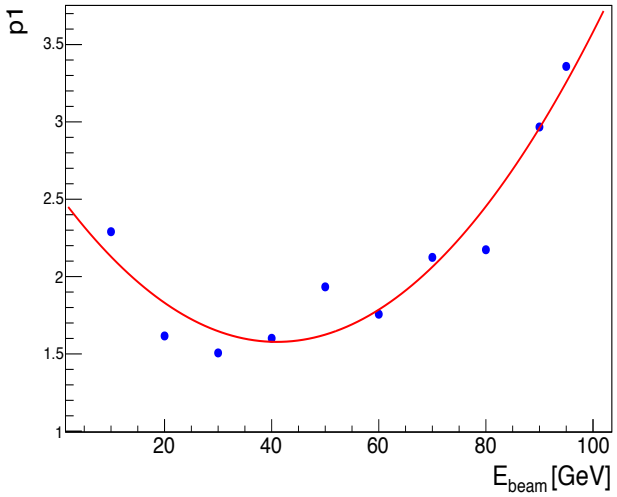
Weight parameters

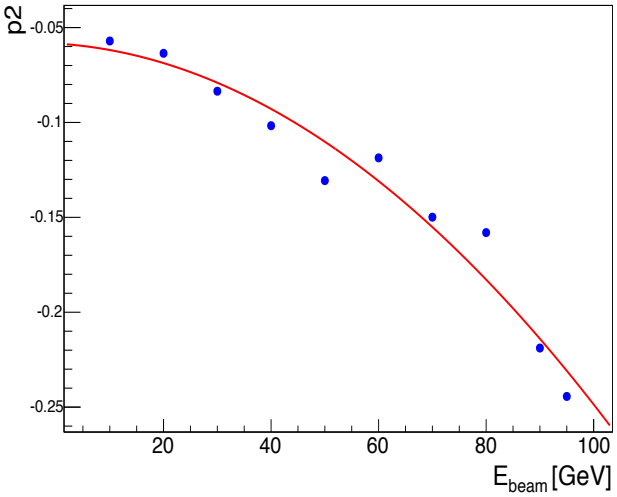


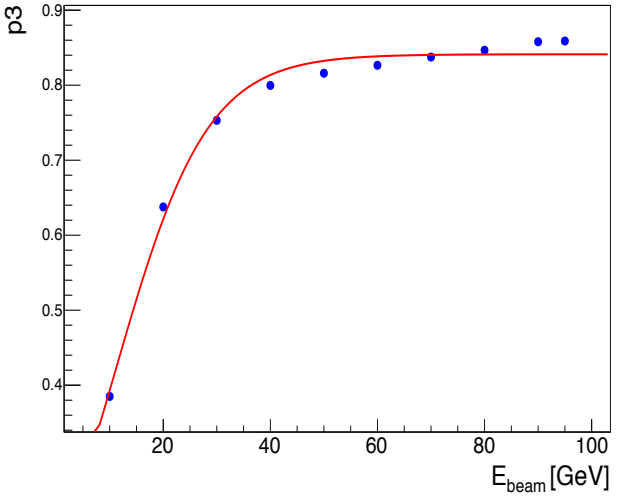
$$\omega(\rho) = p_1.exp(p_2.\rho) + p_3$$

Fitting p_1, p_2, p_3 provides continuous energy dependence

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





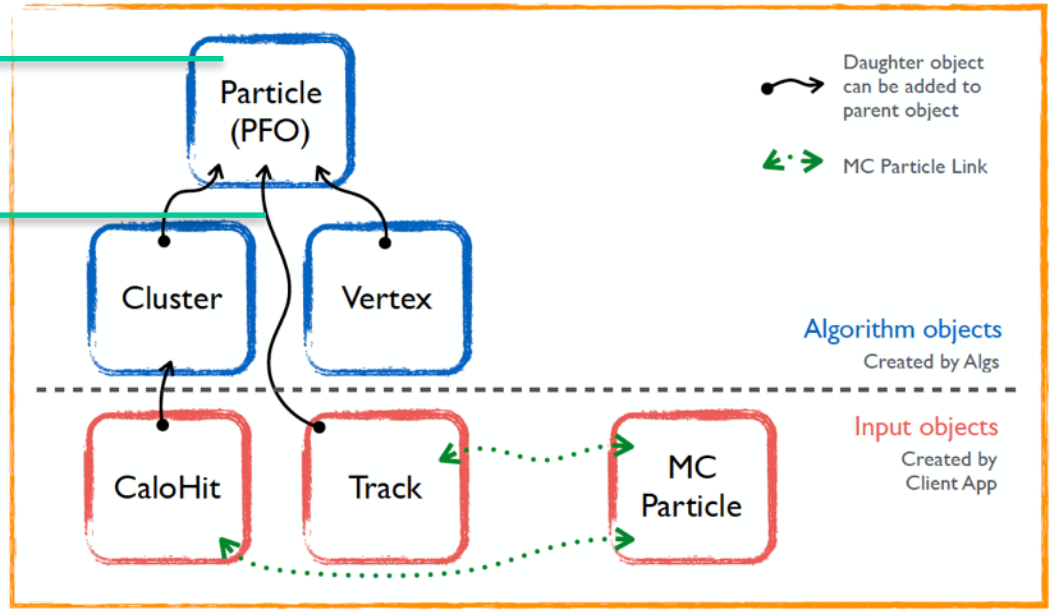


Implementation into Pandora

- 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



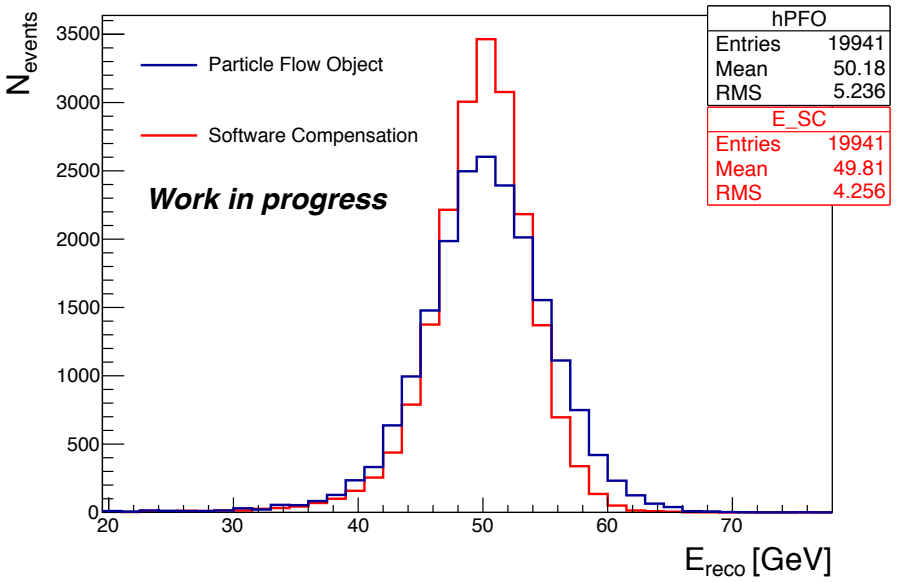
- Flag in MarlinPandora steering to apply software compensation:

NEW

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

Implementation into Pandora

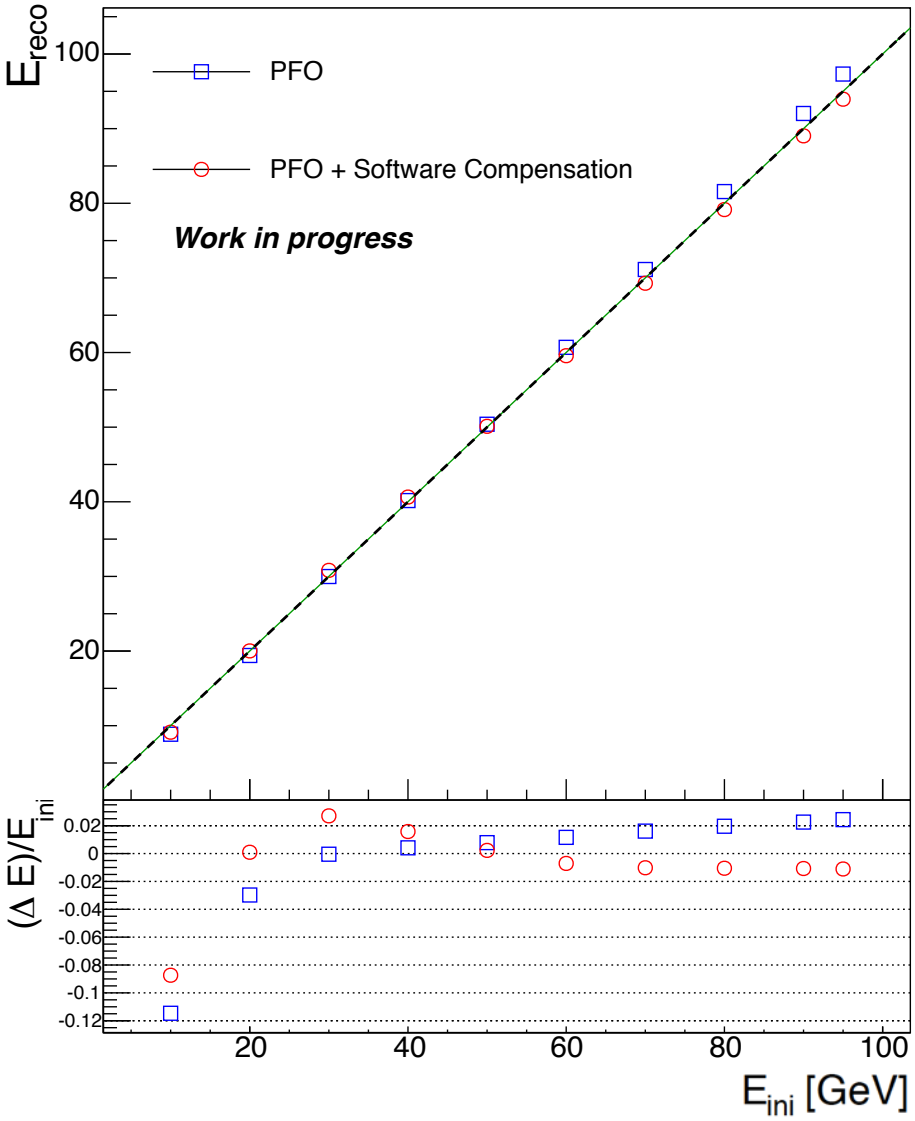
- Correction of neutral hadron PFOs energy
- Initial estimation of cluster's energy used for determination of weights
- Apply to set of Kaon0L and neutron samples from 10 to 95 GeV



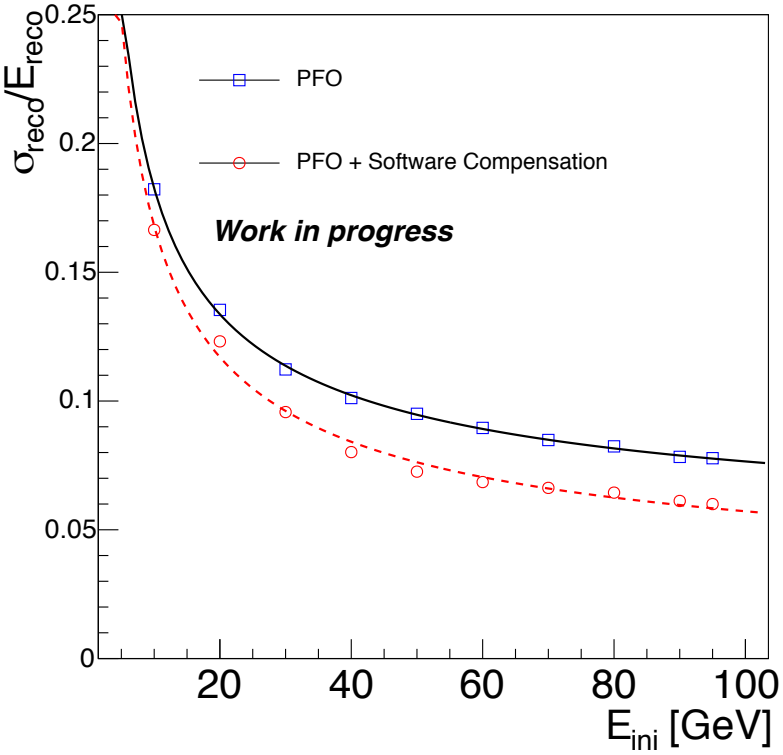
50 GeV Kaon0L

- 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)



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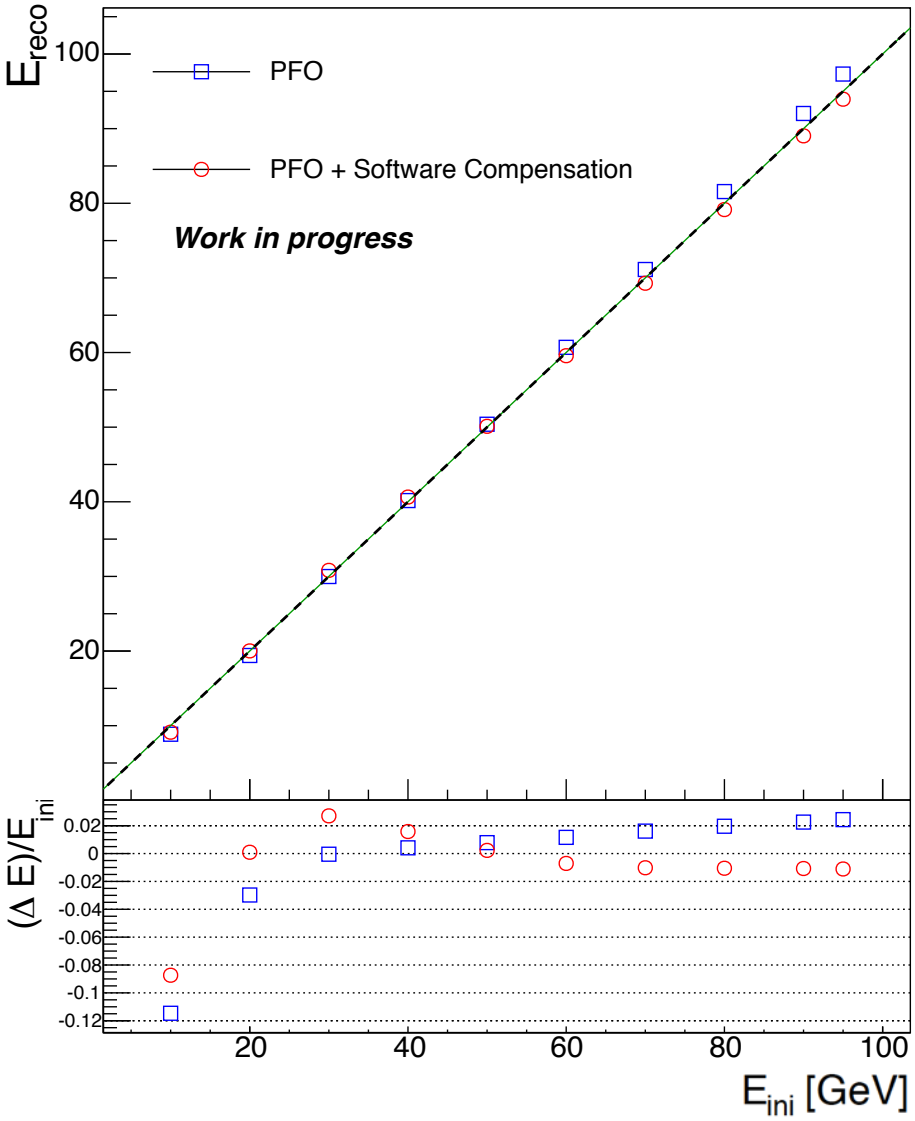

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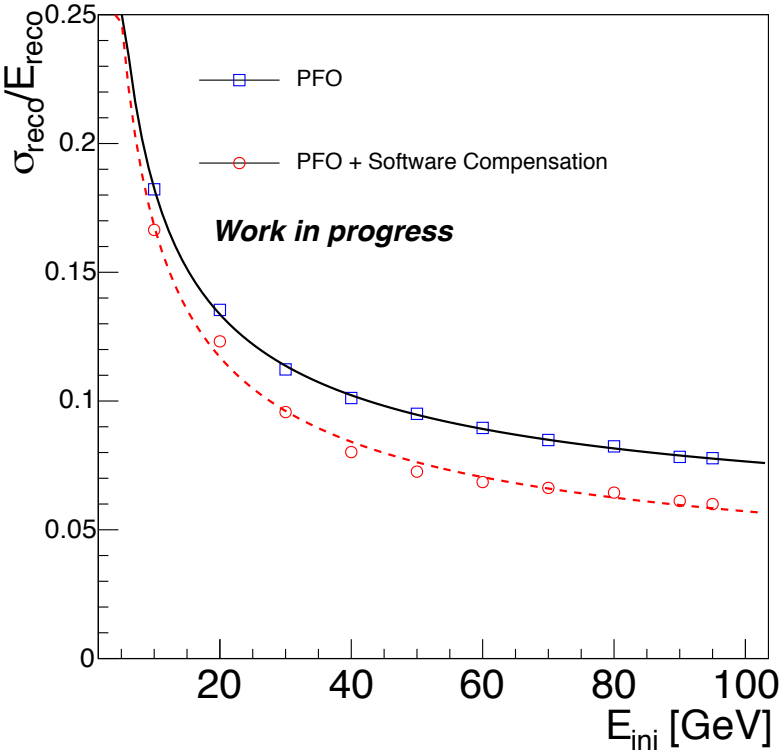
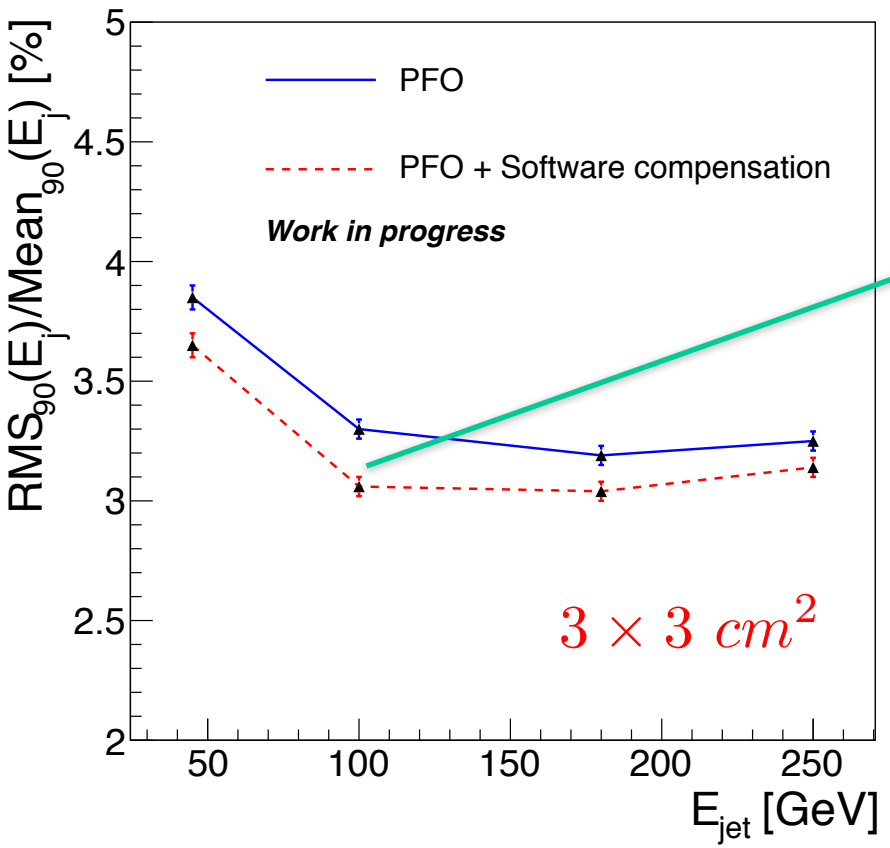
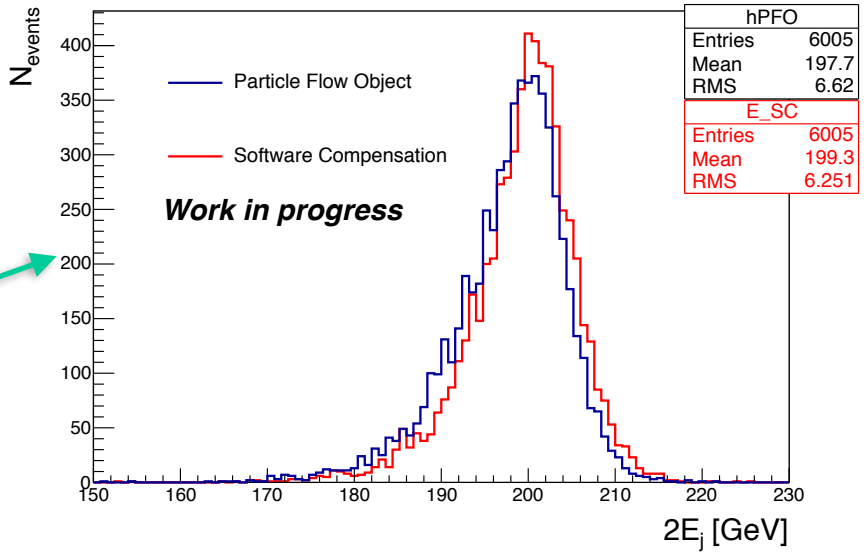


- Testbeam results reproduced
- Overall slightly worse because of missing tail catcher

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

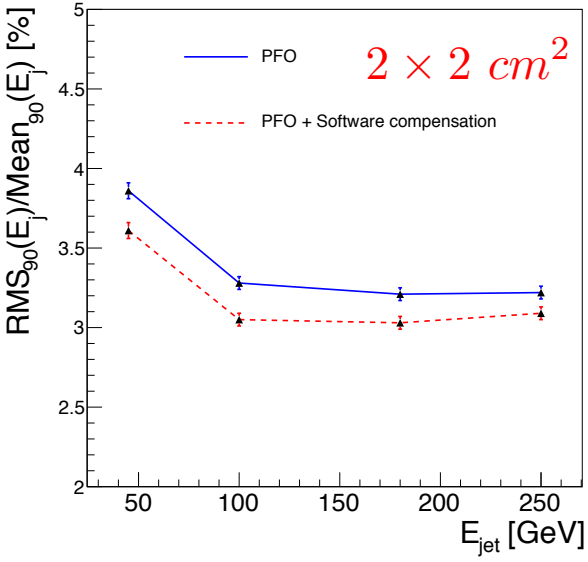


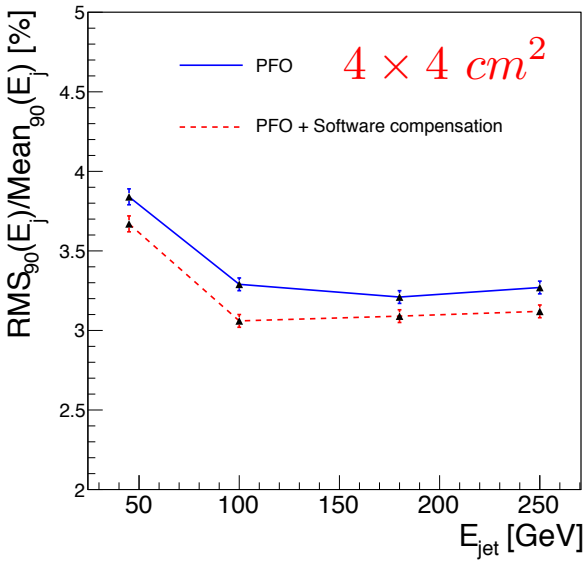


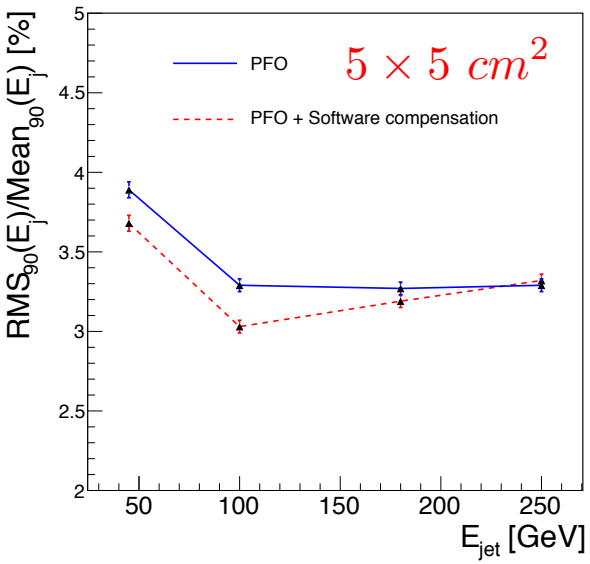
- Reconstructed energy distribution closer to simulated energy and width of distribution smaller
- Improves jet energy resolution in whole range

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

Towards a common SC technique for different types of HCAL

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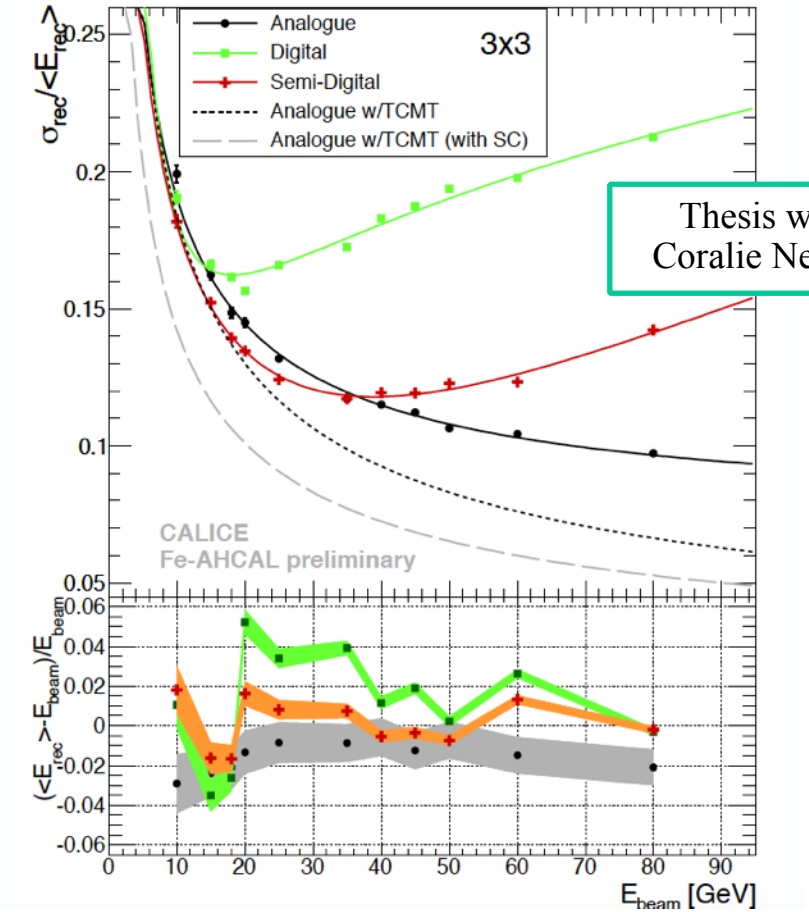
DESY

Semi-digital Reconstruction

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



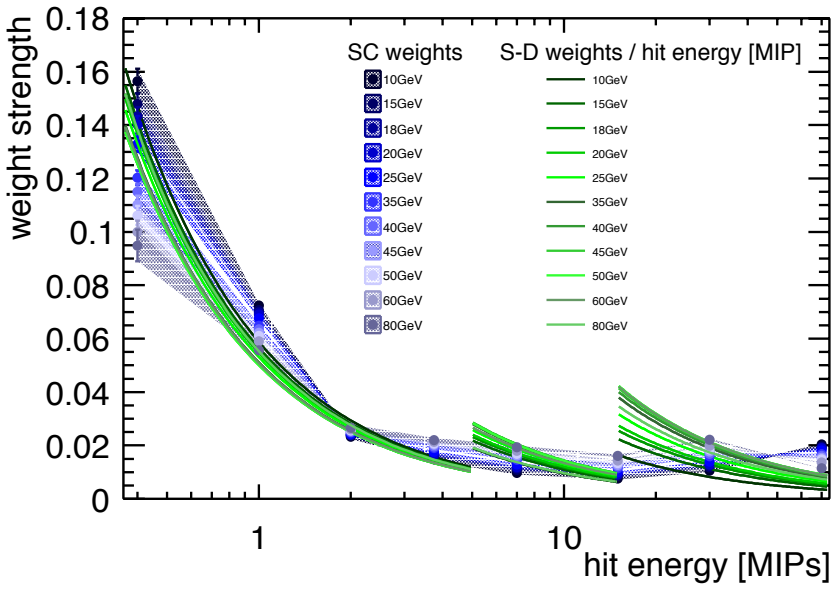
- Reconstructed energy: $E_{SD} = \sum_{bins} \alpha_i . N_i$

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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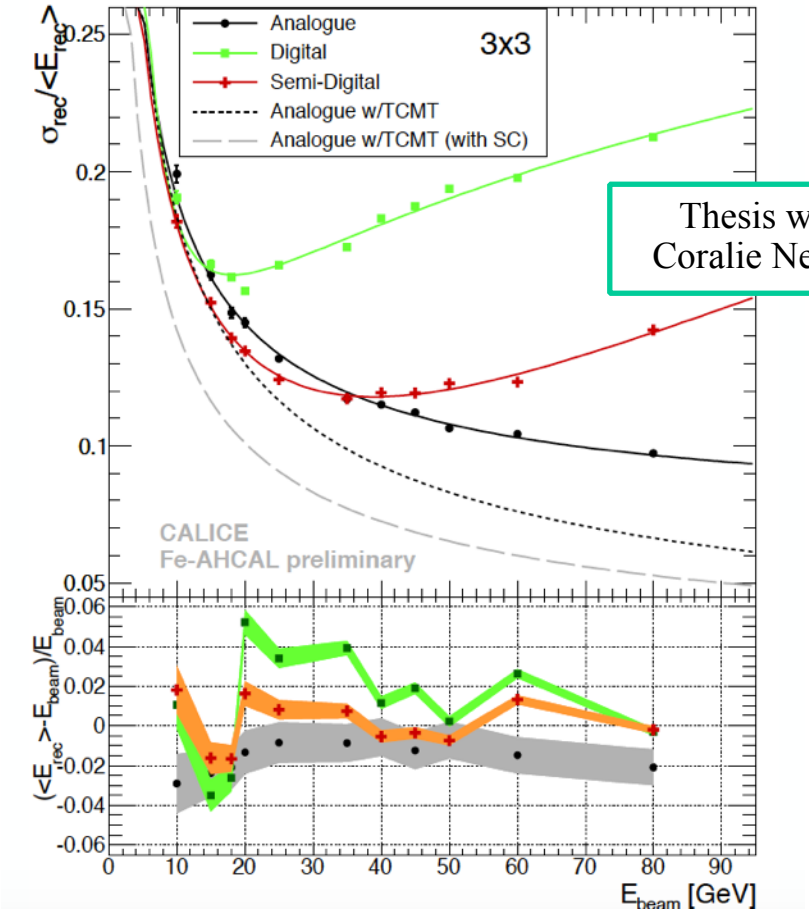

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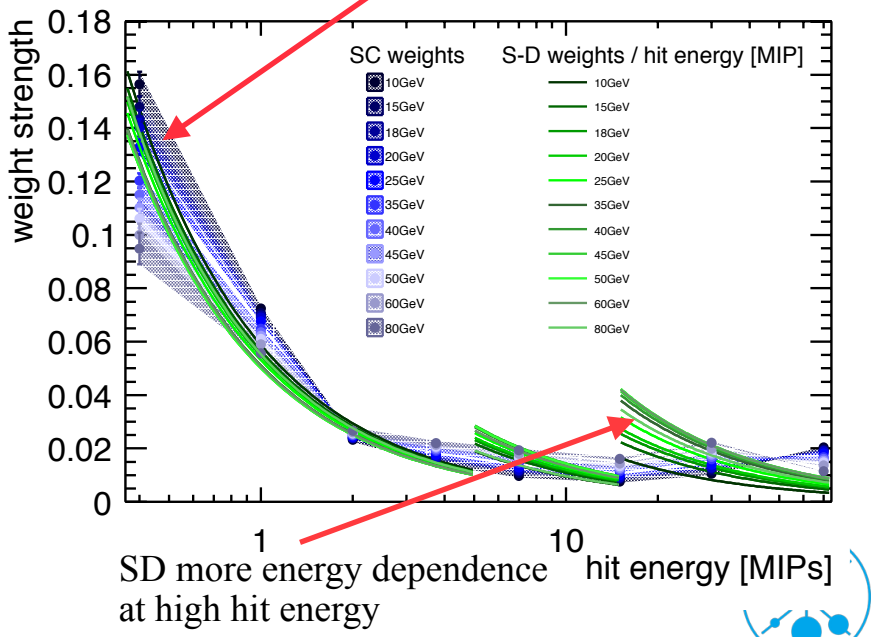
Thesis work in progress
Coralie Neubueser (DESY)

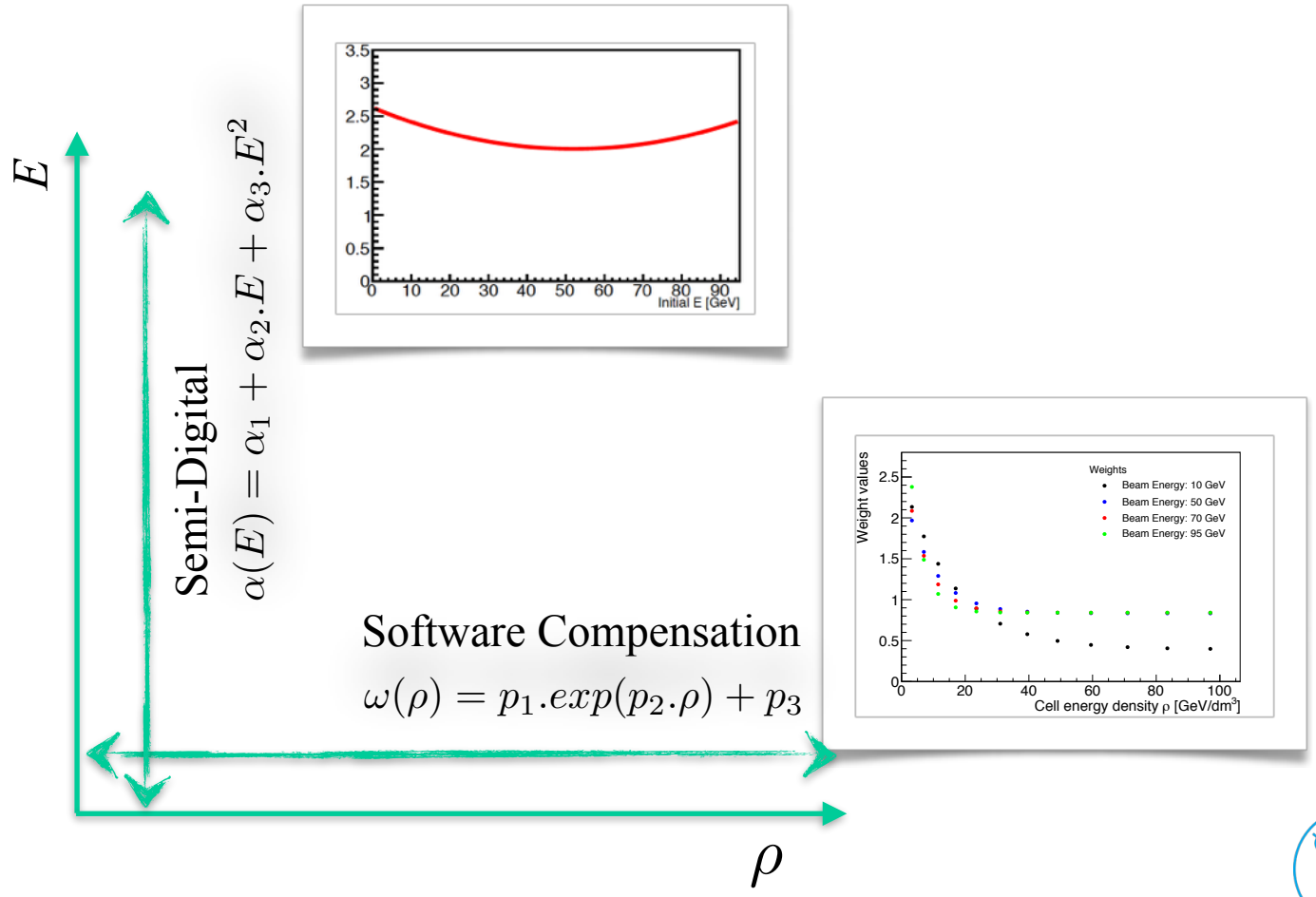
SD less particle energy dependence at small hit energy



SD more energy dependence at high hit energy

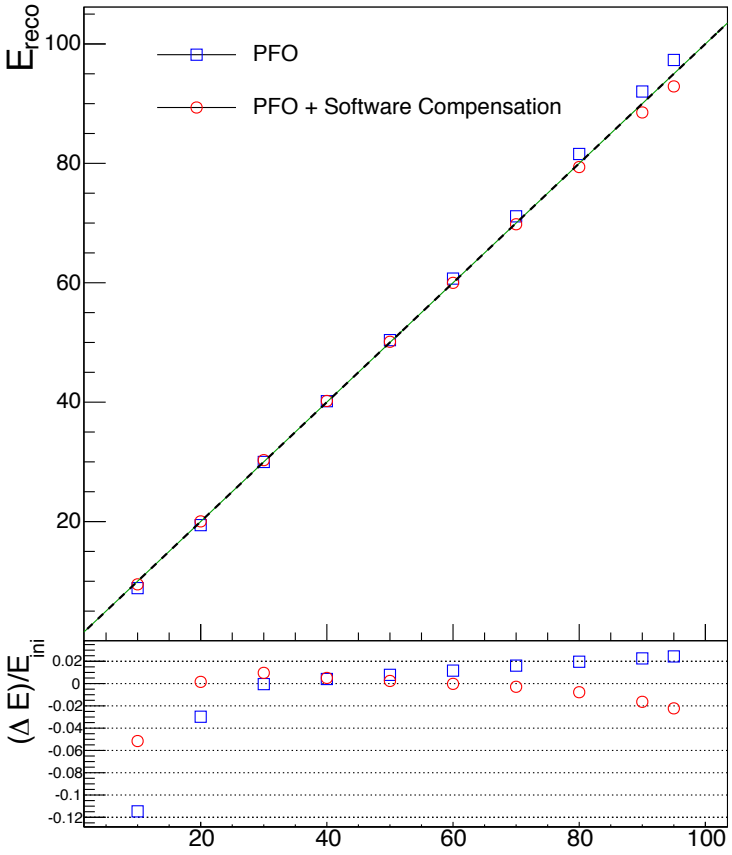
Semi-Digital and Software Compensation

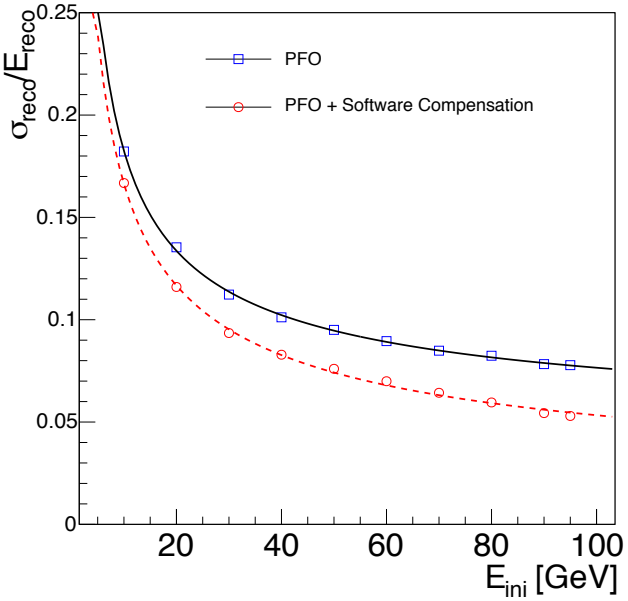
- Semi-Digital: weight optimised as a function of ***particle energy*** E
- Software Compensation: weight optimised as a function of ***hit energy density*** ρ



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)





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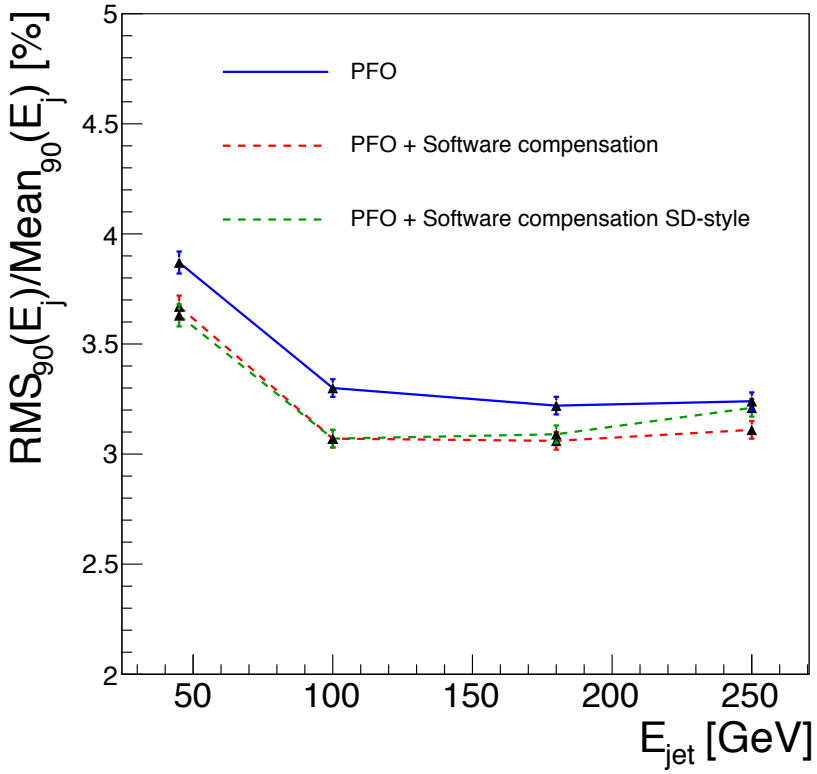


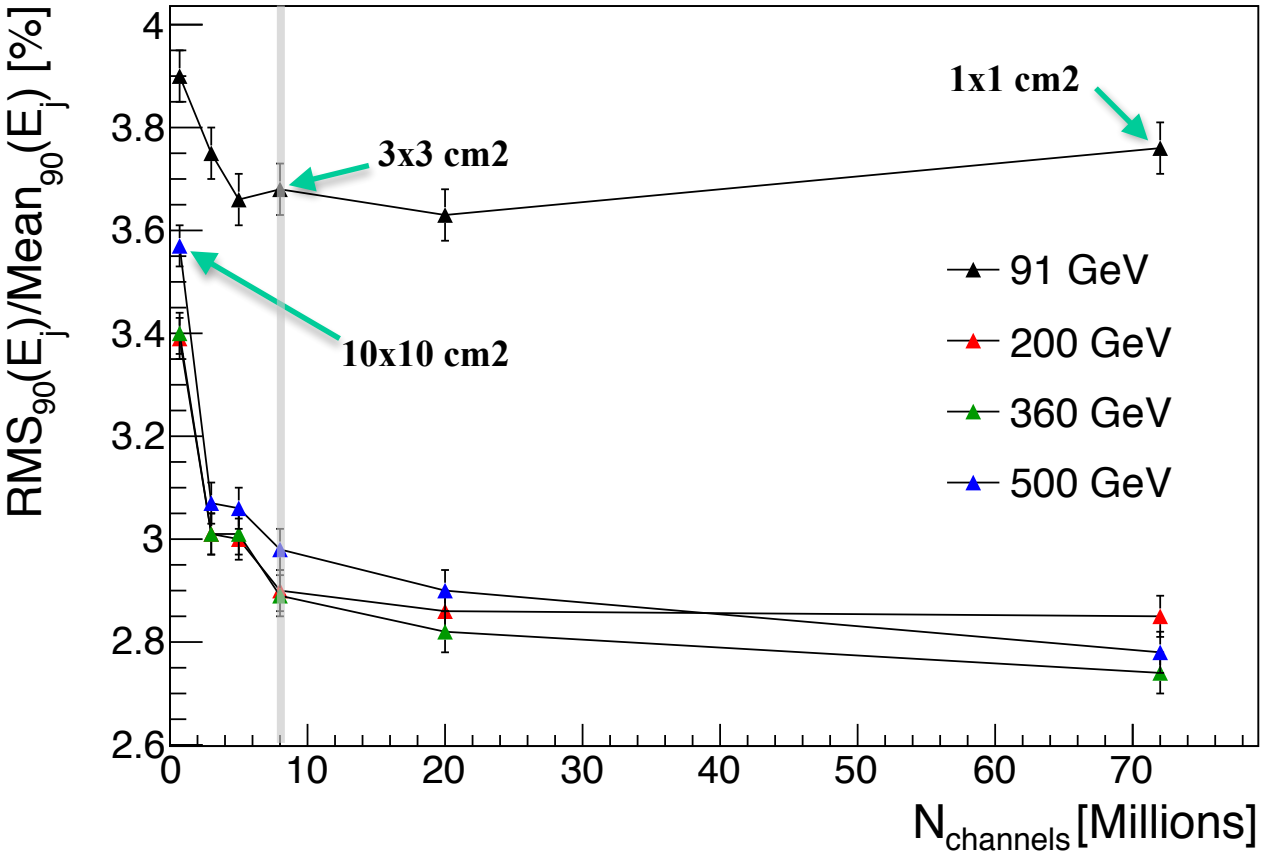
- At jet level gives more or less the same result as previously

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

Summary & Outlook

- *Software compensation and cell size optimisation:*
  - Software compensation *implemented in Pandora*
    - To be put official
  - *Improves* single particle and jet energy resolution
  - Re-clustering step to be investigated
- Towards a common SC technique for different types of HCAL

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

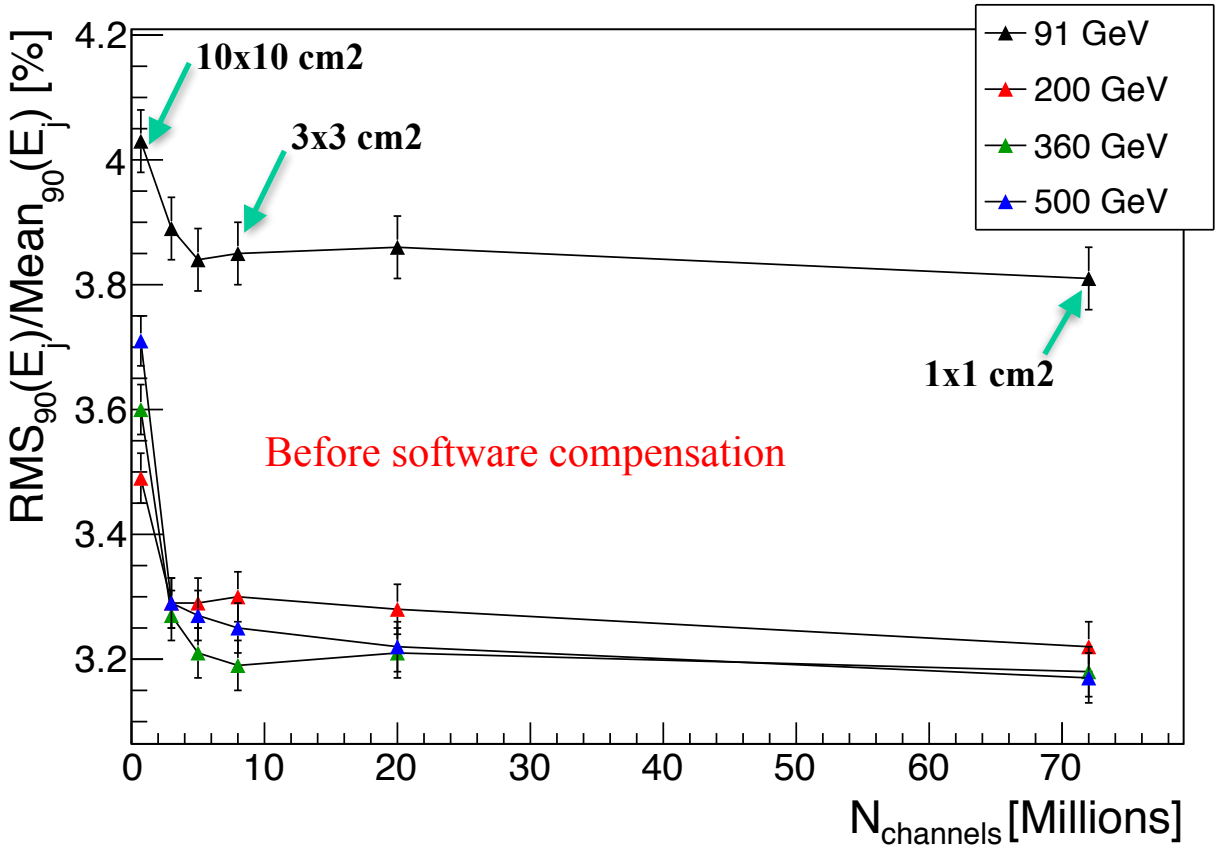
- Third week of December in Cambridge (if visa procedure makes it)

Back-up slides

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:
  - 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

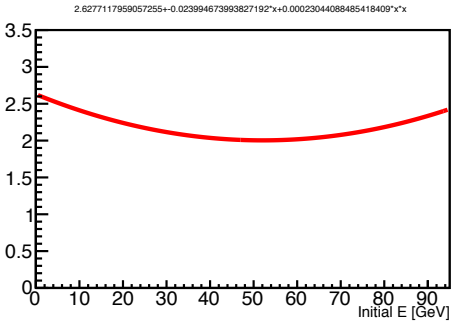
beta = beta1 + beta2*N + beta3*N*N

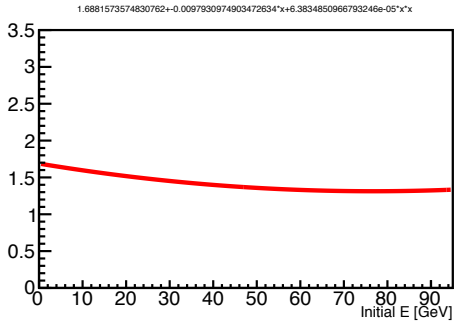
gamma = gamma1 + gamma2*N + gamma3*N*N

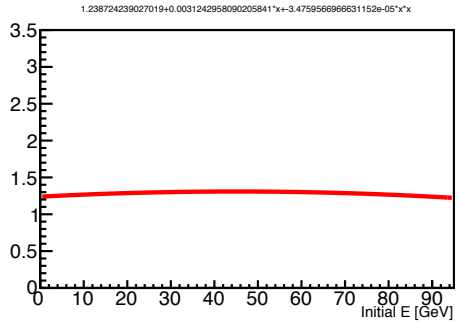
Software compensation mimics Semi-Digital:

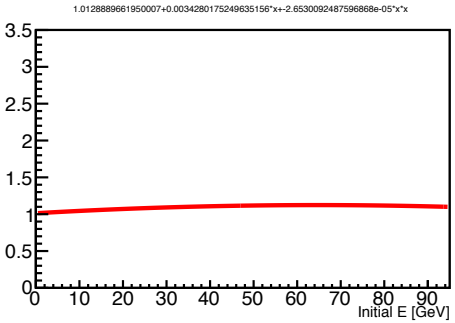
- Define bin
- Energy total = Sum_bin (weight_bin * SumEnergy_bin)
- weight_bin = a + b*E + c*E*E

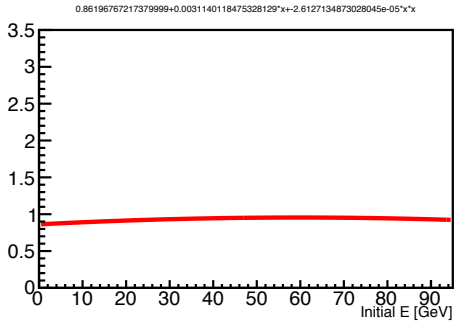
Semi-digital Reconstruction

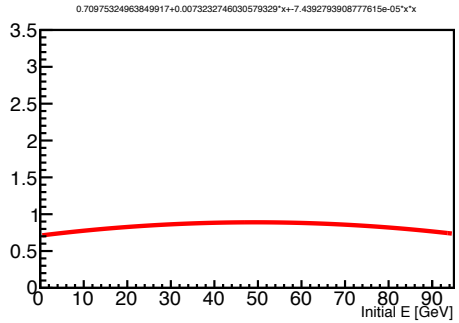


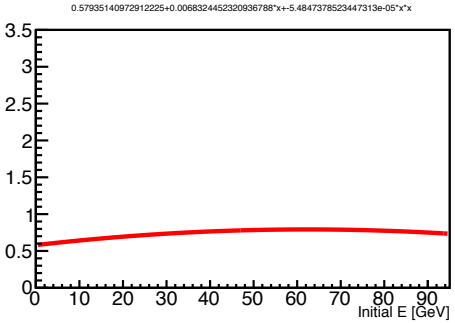


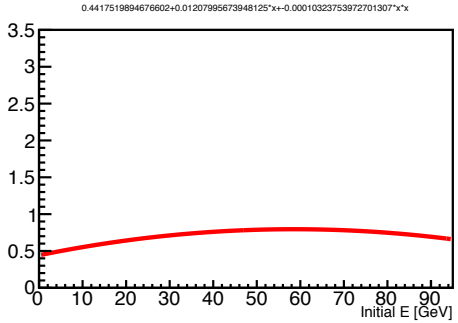


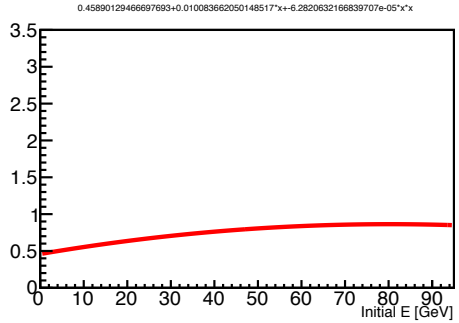












Semi-digital Reconstruction