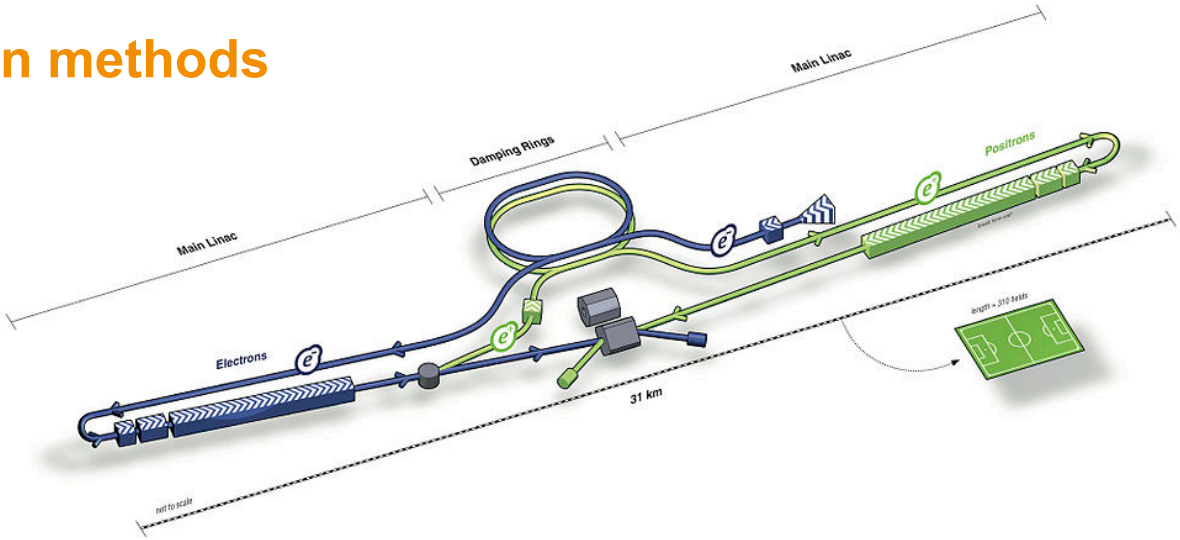
# Comparison of calorimeter concepts for the International Linear Collider (ILC)

## Study of

- **Energy reconstruction methods**
- **Granularities**




Argonne NATIONAL LABORATORY

CALICE Calorimeter for ILC

Coralie Neubüser
DPG Frühjahrstagung
Hamburg, 02.03.16

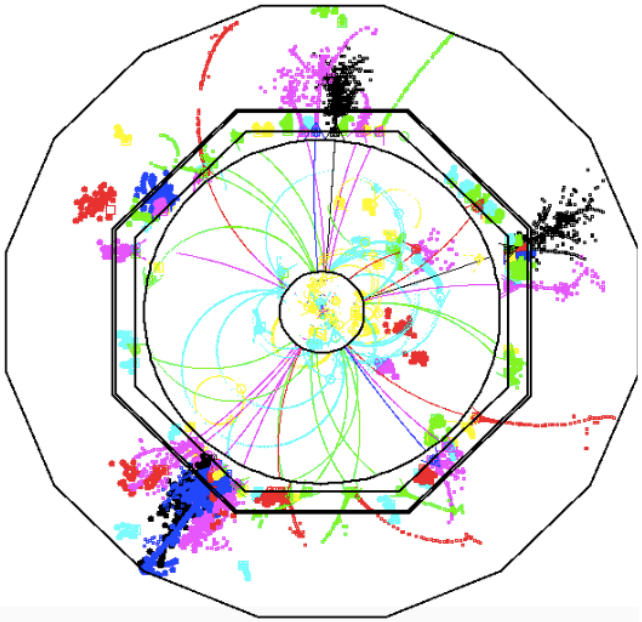
HELMHOLTZ ASSOCIATION

PIER
Eine Partnerschaft der Universität Hamburg und DESY

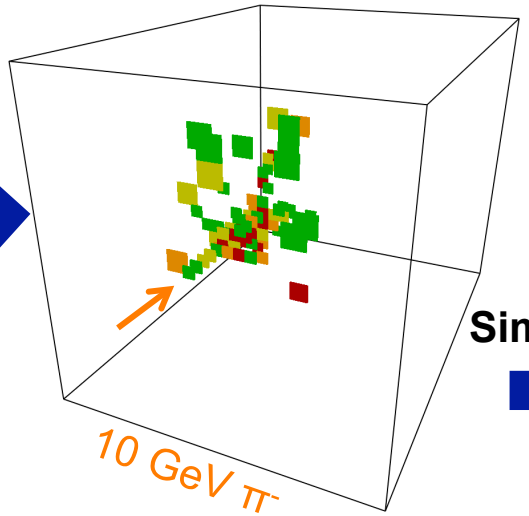
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

DESY

# From International Large Detector to HCAL prototype

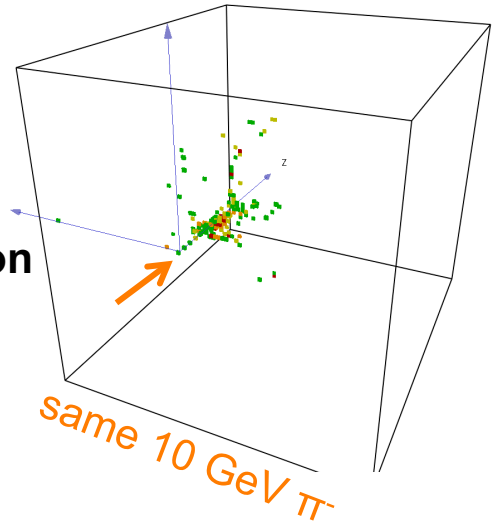


Granularity: max. 3x3cm$^2$ tiles




Simulation

Granularity: 1x1cm$^2$ tiles




**ILD Simulation**, event with Particle Flow particle reconstruction (combination of track + Calorimeter measurements), **with 3x3cm$^2$ HCAL**

→ see Lan's talk

**1m$^3$ Analogue Scintillator-Steel HCAL prototype**, simulations fit data

→ Offers possibility to compare between CALICE HCAL prototypes



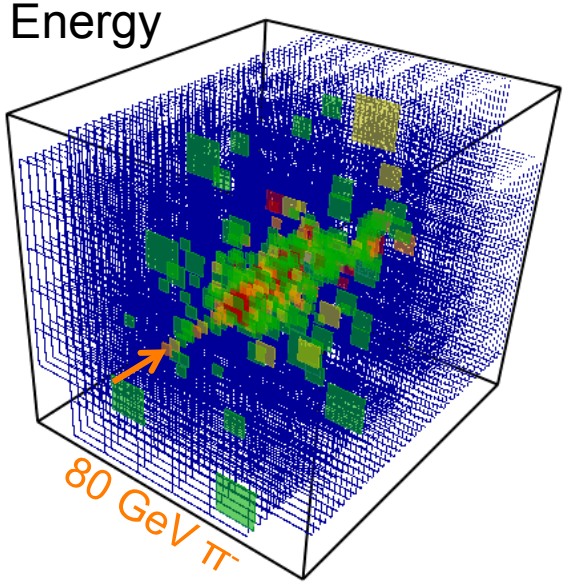
DESY

# CALICE hadron calorimeters overview

- CALICE developed highly granular sampling hadron calorimeters based on Scintillator tiles and Resistive Plate Chambers (RPCs)
  - With analogue, digital and semi-digital read-out

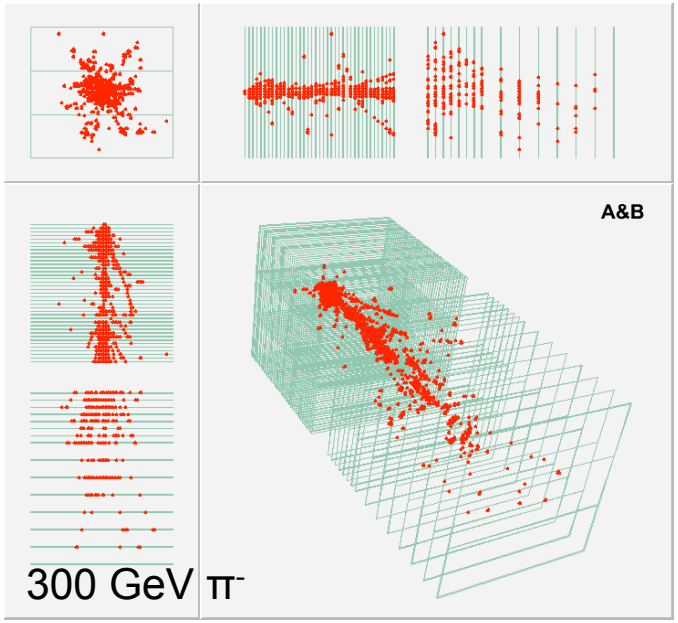
**Analogue**, 12bit readout of max. 3x3cm$^2$ tiles

- Deposited Energy




**Digital**, 1bit readout of 1x1cm$^2$ pads

- Number of hits ~ particle energy




Calice Analysis Note CAN-039

**+ Semi-digital**, 2bit readout

- Number of hits above each of 3 thresholds



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# Energy reconstruction schemes on 3x3 AHCAL data

## > Analogue

- Observable total energy sum $E_{Sum}$ [MIP]

→ Mean linear response

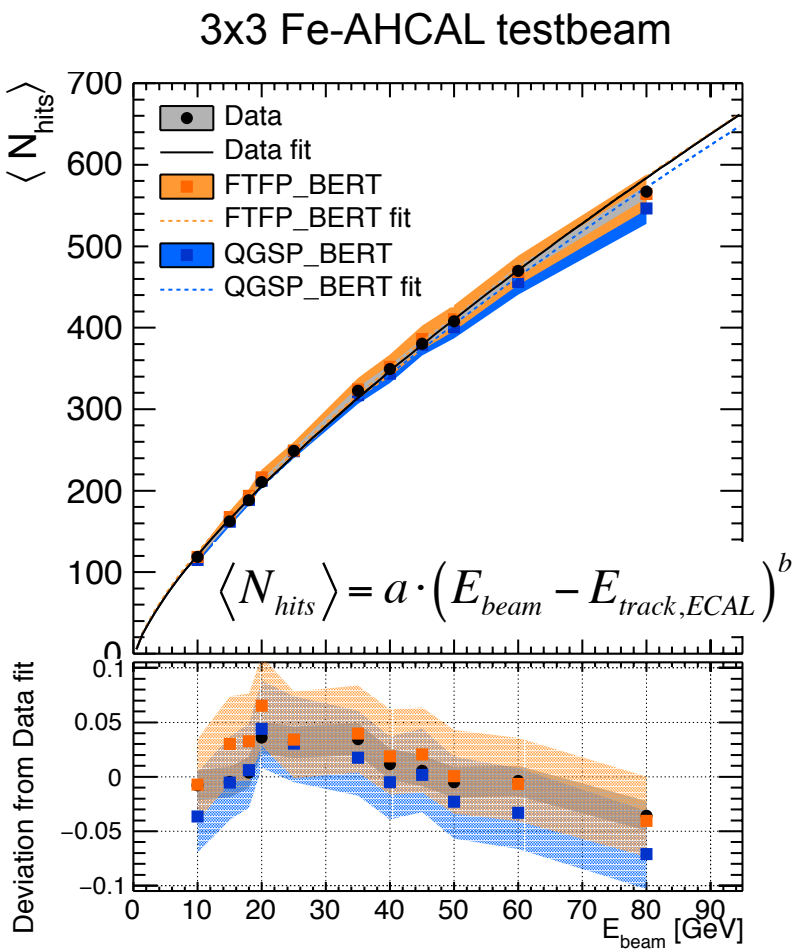
$$E_{rec,analogue} = c \cdot E_{Sum} + E_{track,ECAL}$$

## > Digital

- Observable total number of hits $N_{hits}$

→ Mean response not linear, correction in reconstruction process

$$E_{rec,digital} = \left( \frac{N_{hits}}{a} \right)^{1/b} + E_{track,ECAL}$$



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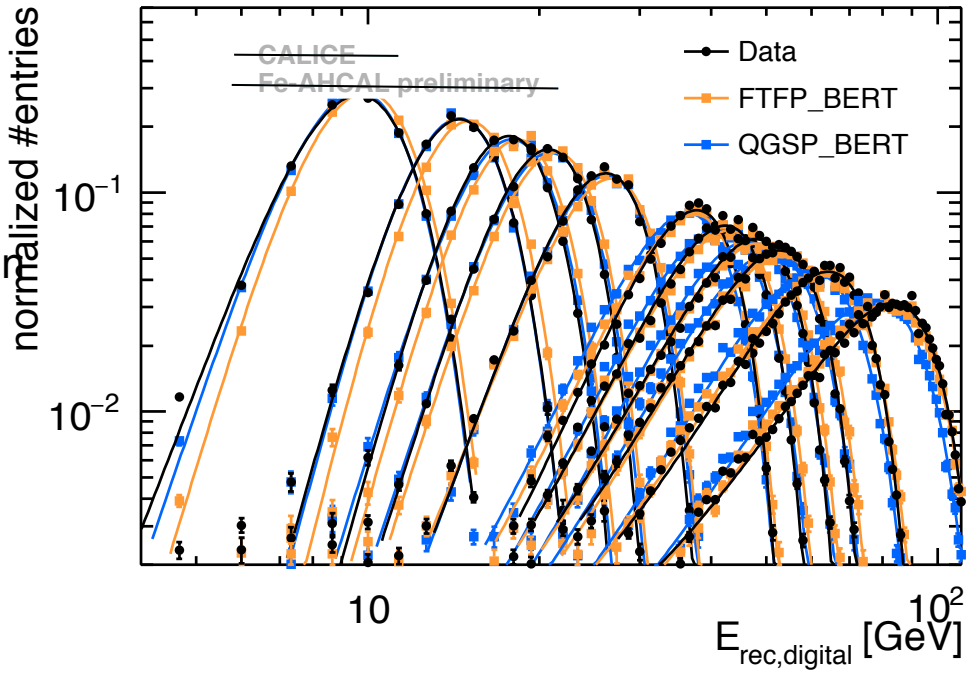


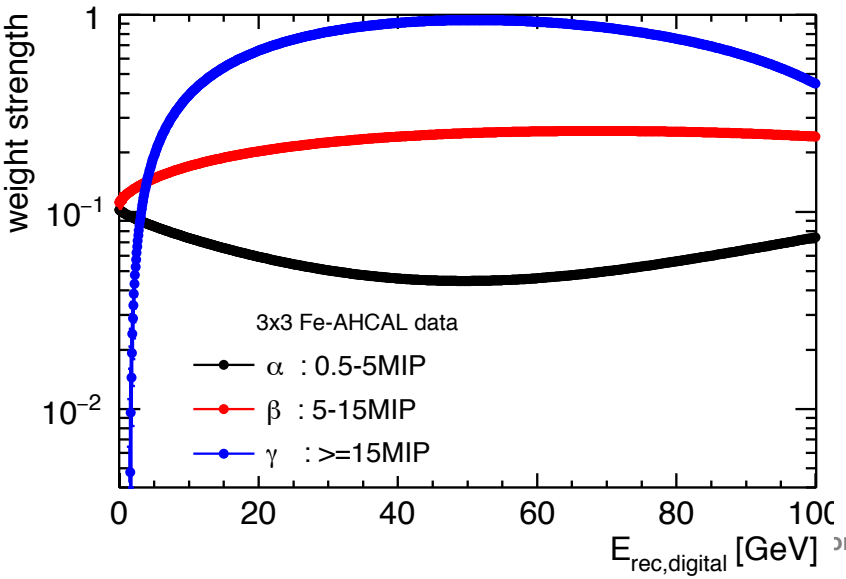
# Energy reconstruction schemes on 3x3 AHCAL data

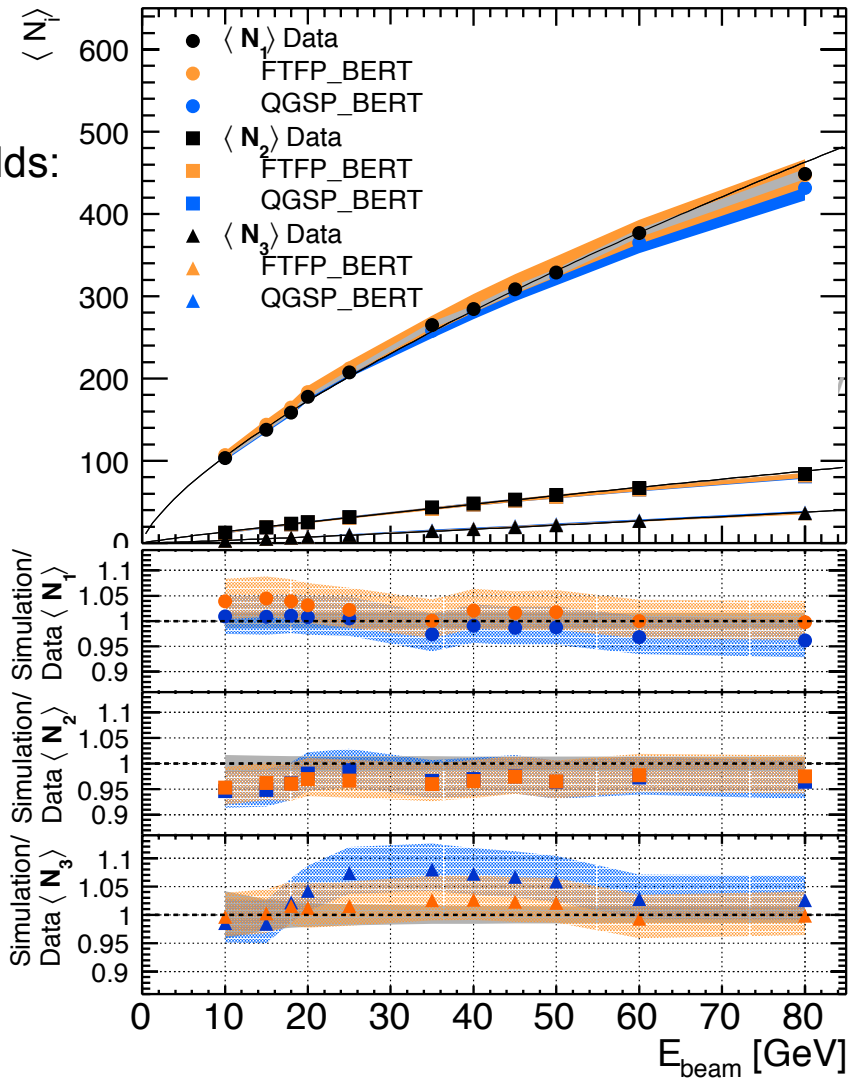
## > Semi-Digital

- Observables number of hits above 3 thresholds:
  $N_1$ = #hits > 0.5 MIP < 5 MIP
  $N_2$ = #hits > 5 MIP < 15 MIP
  $N_3$ = #hits > 15MIP

→ Weights determined for 3 classes of hits

$$E_{rec,SD} = \sum_{i=1}^{3} \alpha_i \left( N_{tot} \right) \cdot N_i$$



# Energy reconstruction schemes on 3x3 AHCAL data

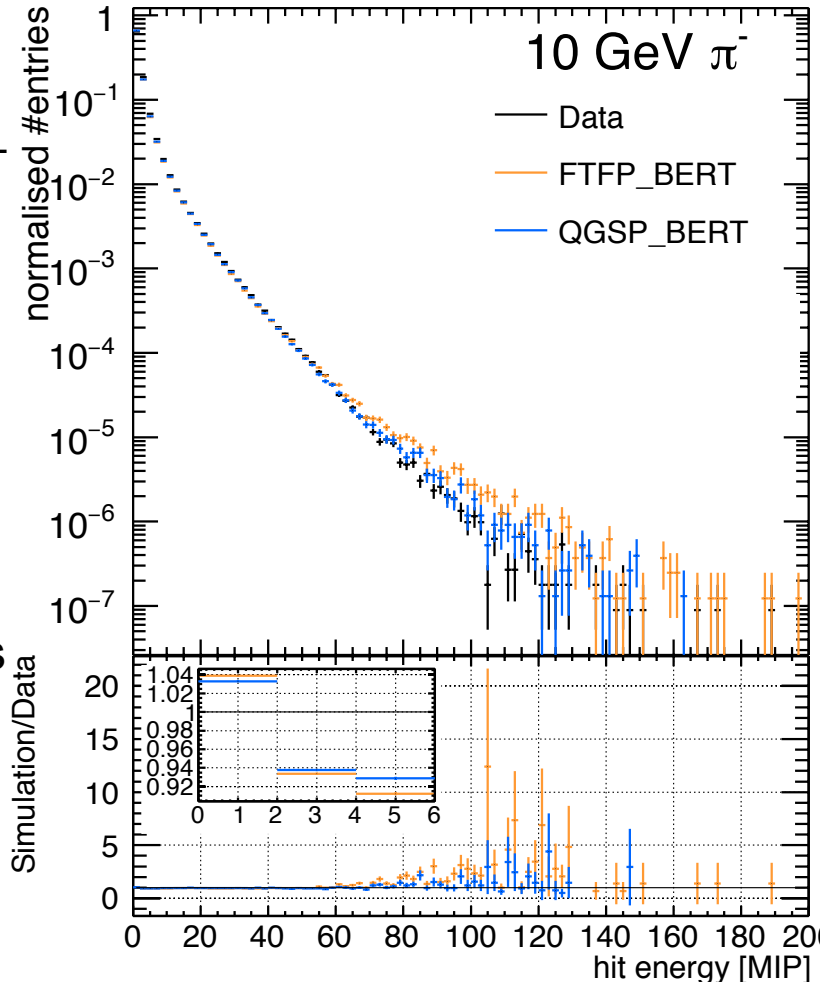
- Software Compensation
  - Resolution is degraded by difference in AHCAL response to em and hadronic parts of shower
  - Observable is individual hit energy

$$E_{rec,SC} = \sum_{i=0}^{Hits} \omega_i \left(E_i, E_{Beam}\right) \cdot E_i$$

- Weight extraction: Bin hit energy → 8 weights
- Parameterising weights energy dependent

$$\omega_j \left(E_j, E_{beam}\right) = a_j + b_j \cdot E_{Sum} + c_j \cdot E_{Sum}^2$$

$$\chi^2 = \frac{\left(\left(\sum_{j=0}^{Bins} \omega_j \left(E_j, E_{beam}\right) \cdot E_j\right) - E_{beam}\right)^2}{E_{beam}}$$



# Energy reconstruction schemes on 3x3 AHCAL data

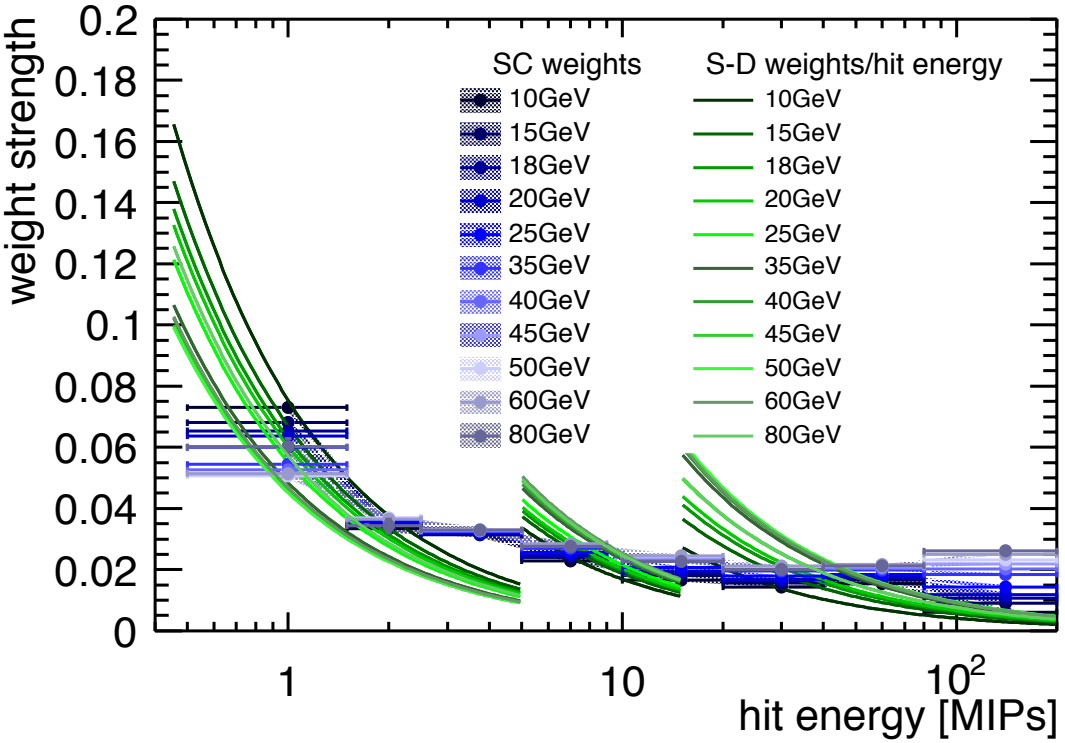
- Compare SC and SD weights

$$E_{rec,SC} = \sum_{i=0}^{Hits} \omega_i \left( E_i, E_{Beam} \right) \cdot E_i$$

$$E_{rec,SD} = \sum_{i=1}^{3} \alpha_i \left( N_{tot} \right) \cdot N_i$$

$$E_i = N_i \cdot hitEnergy_i$$

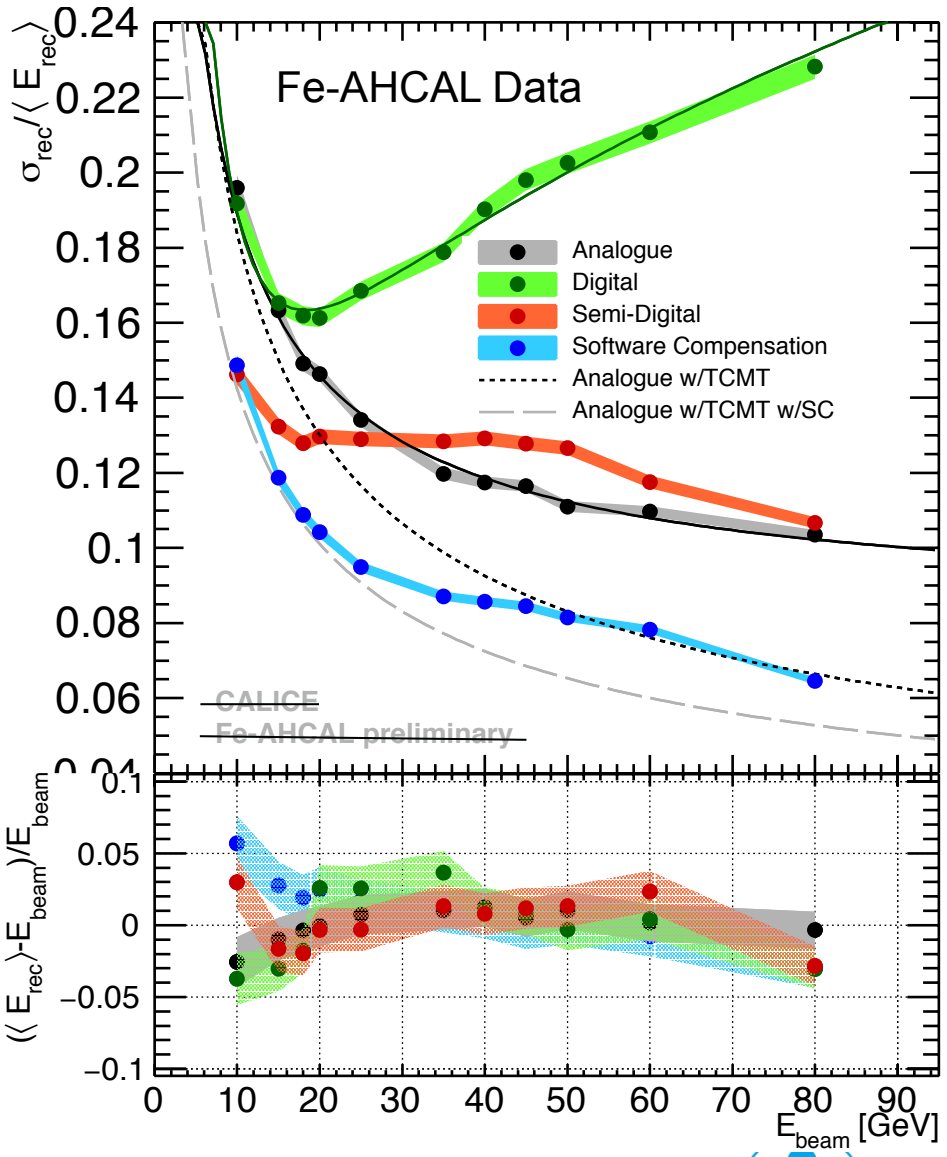
$$\alpha_i \rightarrow \frac{\alpha_i}{hitEnergy_i}$$




- Weight extraction: Bin hit energy → 8 weights
- 1/hitEnergy dependence nicely agreement for small hit energies, but not for the higher ones

# Energy Resolution

- **Digital**
  - Granularity of max. 3x3 cm$^2$ not sufficient
- **Semi-digital**
  - Semi-digital resolution better than analogue? → weighting include Software Compensation strategy
- **Software Compensation**
  - Best results
  - New algorithm achieves the same resolution as previous analysis including TCMT
  - Difference in higher energies originate from fitting method (including tails due to leakage)



# Energy Resolution of 1x1 AHCAL simulation

- Major change 3x3→1x1:
  - Threshold lowered to 0.3MIP
  - No noise (realistic nowadays!)

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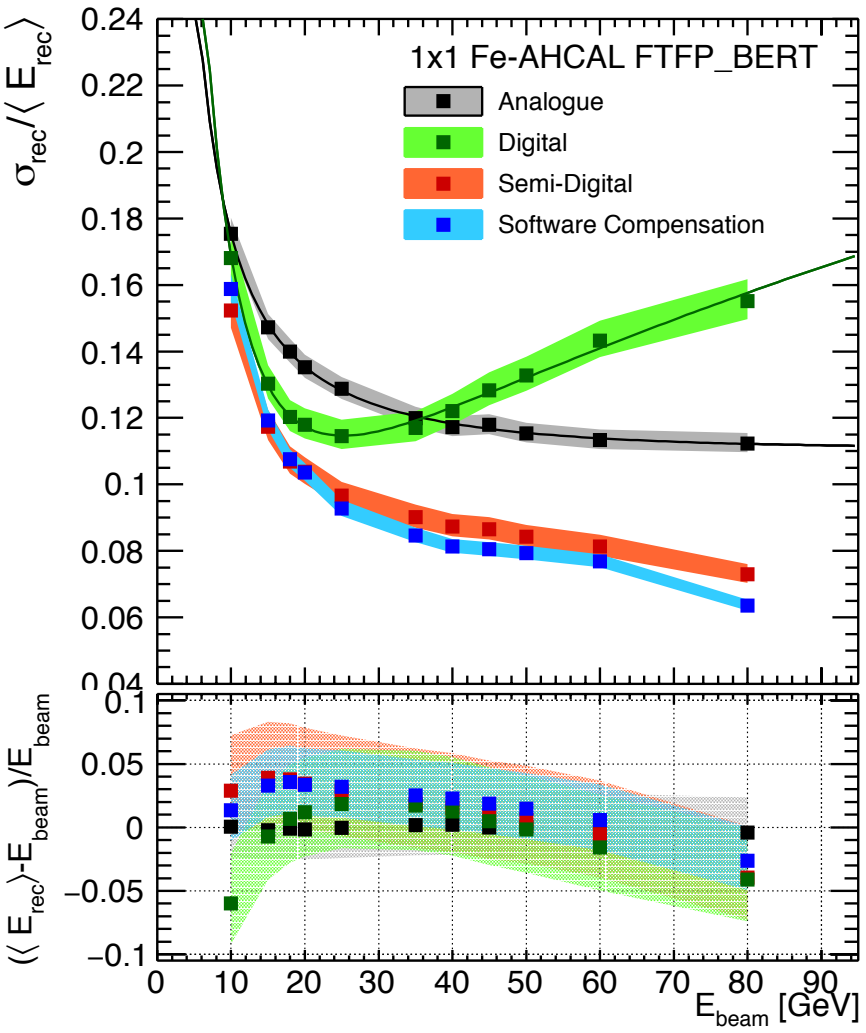
- **Analogue**
  - For reconstruction, analogue response fitted
- **Digital**
  - Better resolution than Analogue reconstruction for energies below 30 GeV due to Landau fluctuations?
- **Semi-Digital & Software Compensation**
  - Semi-digital resolution achieves ~Software Compensation



# Messages

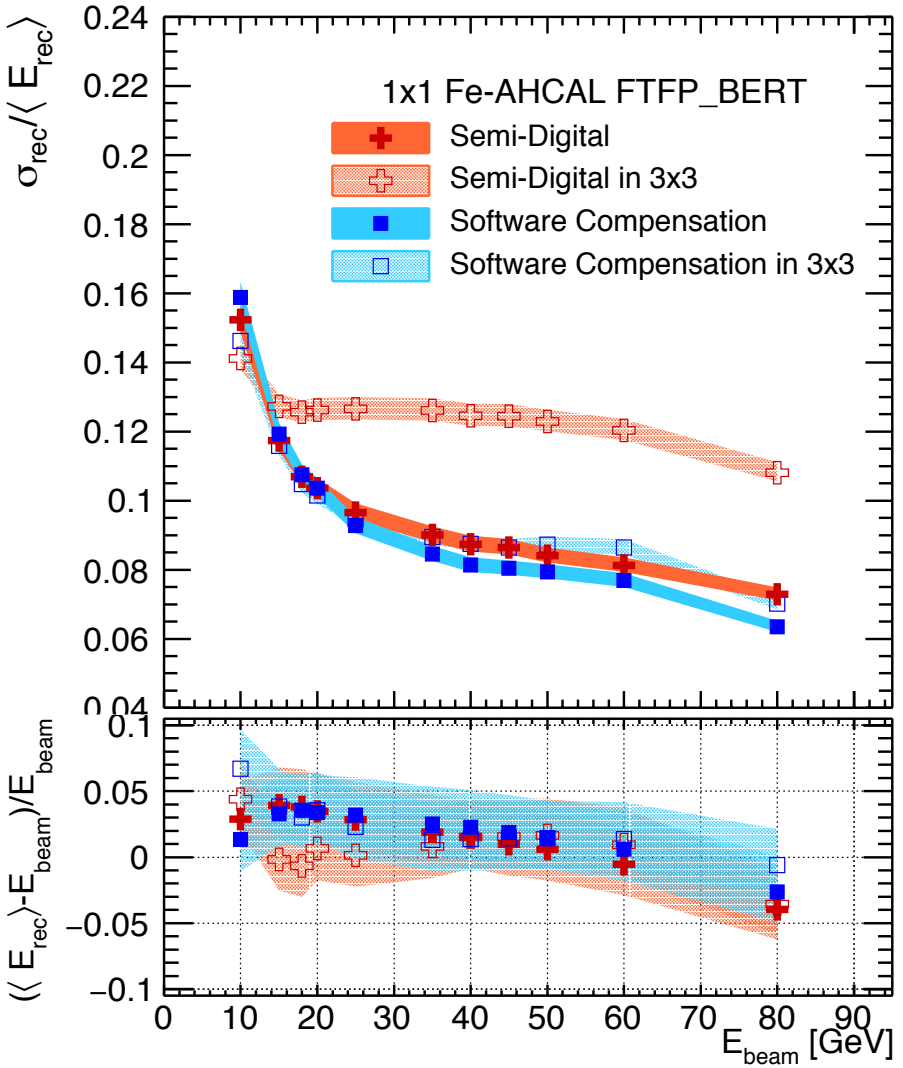
1. Particle flow reconstruction depends on granularity

2. Optimal single particle energy resolution needs:
    1. Granularity matches read-out
    2. Sensitivity/efficiency of active media

**THANK's for the attention!**

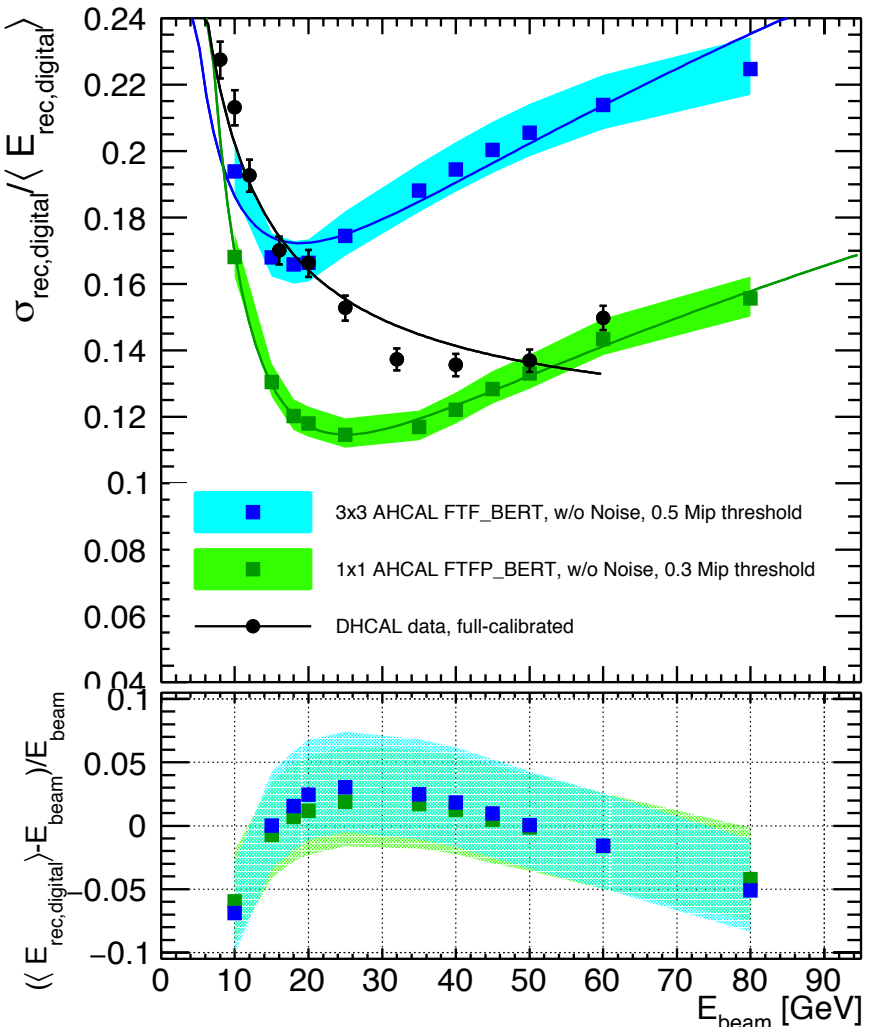
# Comparison of 1x1 AHCAL MC & 3x3 AHCAL Data

- Same reconstruction method
- Semi-Digital energy reconstruction very dependent on granularity
- 1x1 Semi-Digital equivalent to 3x3 Software Compensation
- Software Compensation doesn't improve much with higher granularity



# Comparison of 1x1 AHCAL MC & DHCAL Data

- Same reconstruction method
- FTFP_BERT Simulation for 3x3 and 1x1 AHCAL
  - digitised without noise!
  - Different thresholds → impact on resolution
- Agreement with DHCAL Data in 50 and 60 GeV point
- Hint that higher efficiency of Scintillator tiles improves digital reconstruction for low energies



# Comparison of 1x1 AHCAL MC & SDHCAL Data

- Same reconstruction method
- FTFP_BERT Simulation for 3x3 and 1x1 AHCAL
  - Different thresholds → impact on resolution
- SDHCAL data taken with 10 more active layers!
  - Nevertheless 1x1 AHCAL MC better
- Hint that higher efficiency of Scintillator tiles improves digital reconstruction for low energies