CAN-049a: Comparison of Energy Reconstruction Schemes and Different Granularities in the CALICE AHCAL

Changes since CALICE Meeting Kyushu

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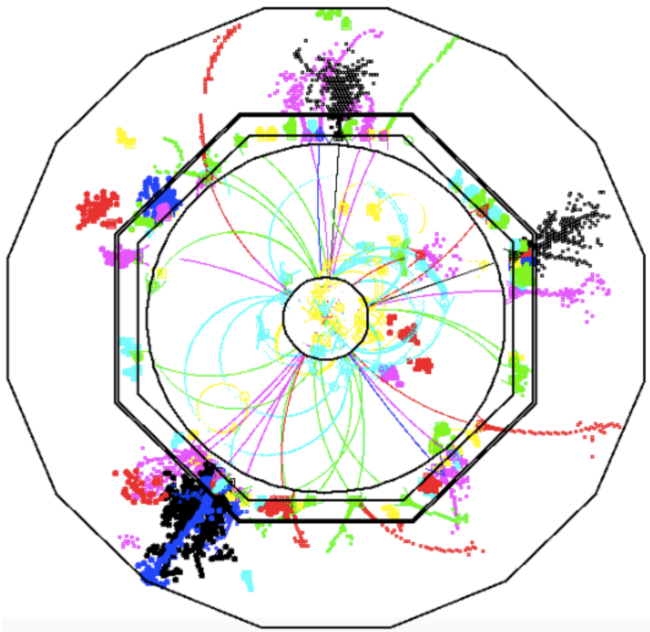
CALICE Day
Santander, 01.06.16

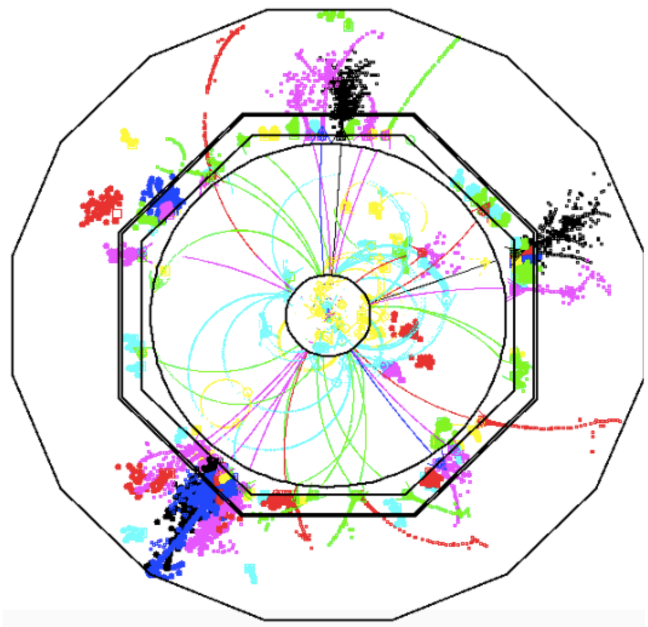
Eine Partnerschaft der Universität Hamburg und DESY

Particle Flow Detectors for e^+e^- Colliders

ILD Simulation with 3x3cm^2 HCAL



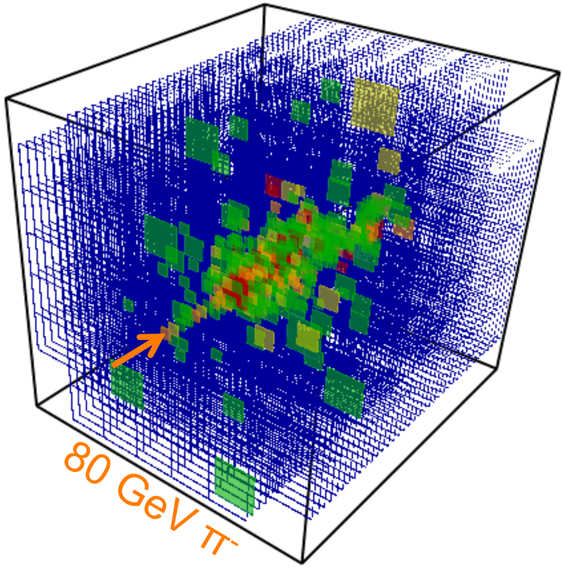
ILD Simulation with 1x1cm^2 HCAL



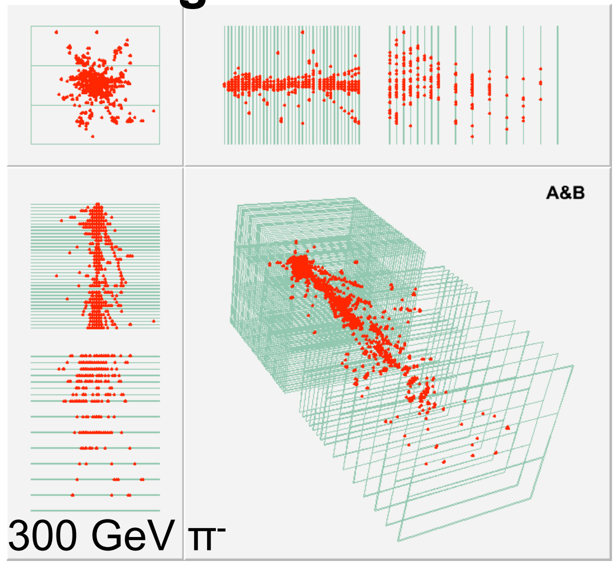
- Particle flow reconstruction (combination of track + Calorimeter measurements) depends on granularity for pattern recognition
- **Which granularity and energy information is needed?**

CALICE AHCAL, DHCAL & SDHCAL

Analogue HCAL

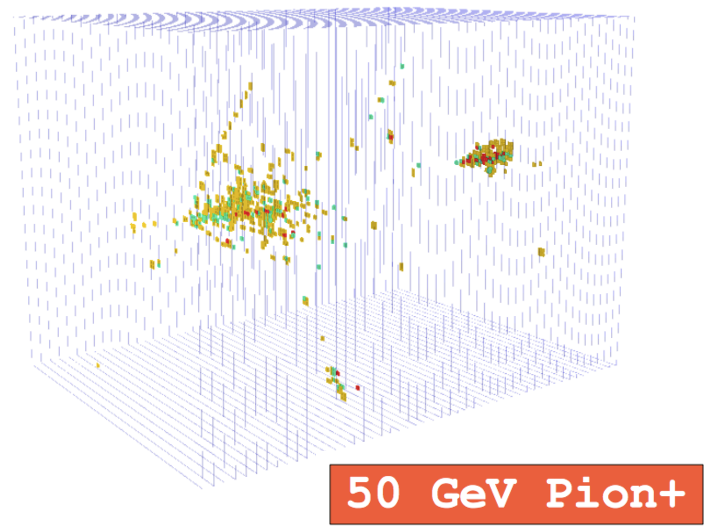


Digital HCAL



Calice Analysis Note CAN-039

Semi-Digital HCAL



GRPC SDHCAL Analysis Meeting 2012, "SDHCAL Software summary", Y. Haddad

Fe-AHCAL	Fe-DHCAL	Fe-SDHCAL
Scintillator	RPC, gaseous	RPC, gaseous
12bit readout	1bit readout	2bit readout
3x3cm^2	1x1cm^2	1x1cm^2

Readout/Energy reco: **can be studied in AHCAL data**

Granularity: **can be studied in AHCAL MC**

Energy Reconstruction Schemes

> Analogue

- Observable: energy sum E_{sum} [MIP]

→ Mean linear response

$$E_{rec,analogue} = c \cdot E_{sum}$$

> Digital

- Observable: total number of hits N_{hits}

→ Mean response not linear, correction in reconstruction process

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

> Analogue Software Compensation

- Resolution is degraded by difference in AHCAL response to em and hadronic parts of shower (e/π=1.19)
- Observable is individual hit energy e_i

$$E_{rec,SC} = \sum_{j=1}^{N_{hits}} \omega\left(e_j, E_{sum}\right) \cdot e_j$$

> Semi-Digital

- Observables: number of hits above 3 thresholds:

N_1: 0.5 MIP < hits < 10.5 MIP

N_2: 10.5 MIP < hits < 57 MIP

N_3: 57 MIP < hits

$$N_{hits} = N_1 + N_2 + N_3$$

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

CAN-049a

- Study of energy reconstruction schemes with Fe-AHCAL testbeam data
- Study of impact of granularity on energy reconstruction going from $3x3cm^2 \rightarrow 1x1cm^2$ tiles in Fe-AHCAL simulation

- Improvements done since last CALICE Meeting:
  - Optimisation of thresholds set for semi-digital energy reconstruction

- Approved, published on CALICE website and results shown at CALOR

https://twiki.cern.ch/twiki/pub/CALICE/CaliceAnalysisNotes/CAN-049a.pdf

Shown in Kyushu: Energy Resolution of 3x3 Fe-AHCAL

> Digital

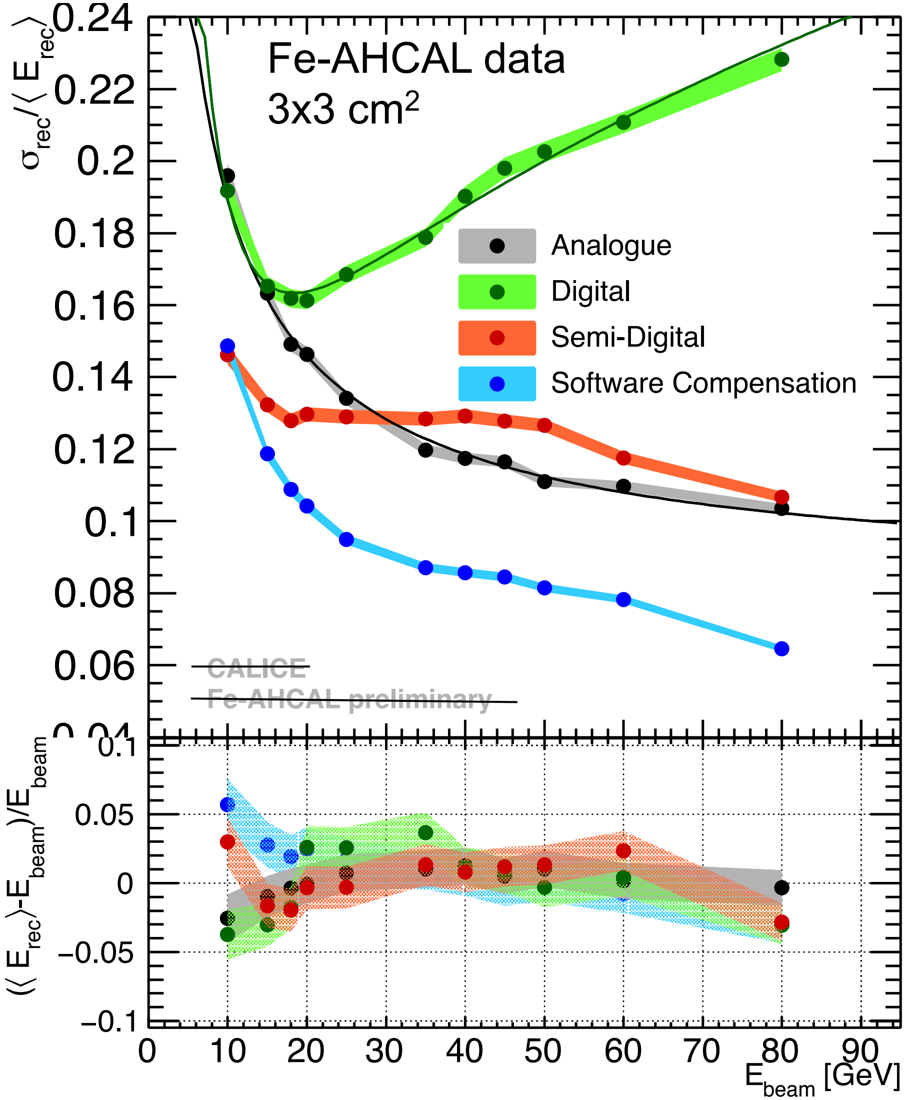
- Granularity of max. 3x3 cm^2 not sufficient

> Semi-digital

- Better than Analogue for beam energies below 32GeV

> Software Compensation

- Best results



Shown at CALOR: Energy Resolution of 3x3 AHCAL

> Digital

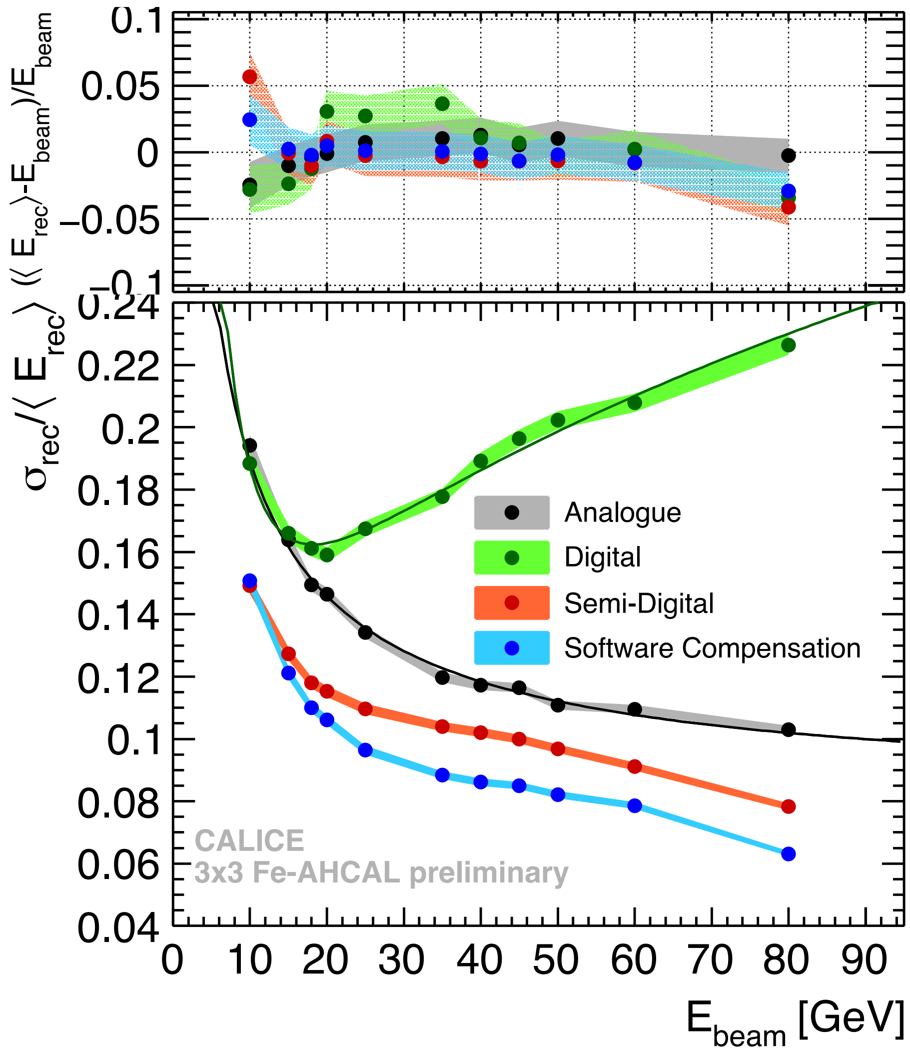
- Resolution degraded by saturation stepping in at low energies

> Semi-Digital

- Better than Analogue over whole energy range, although less signal information
- Included weighted scheme, not used in analogue reconstruction yet

> Software Compensation

- Best results



Semi-Digital Energy Reconstruction

> Threshold setting

- Observables number of hits above 3 threshol
  t_1,t_2 and t_3 :

  N_1: t_1 < hits < t_2

  N_2: t_2 < hits < t_3

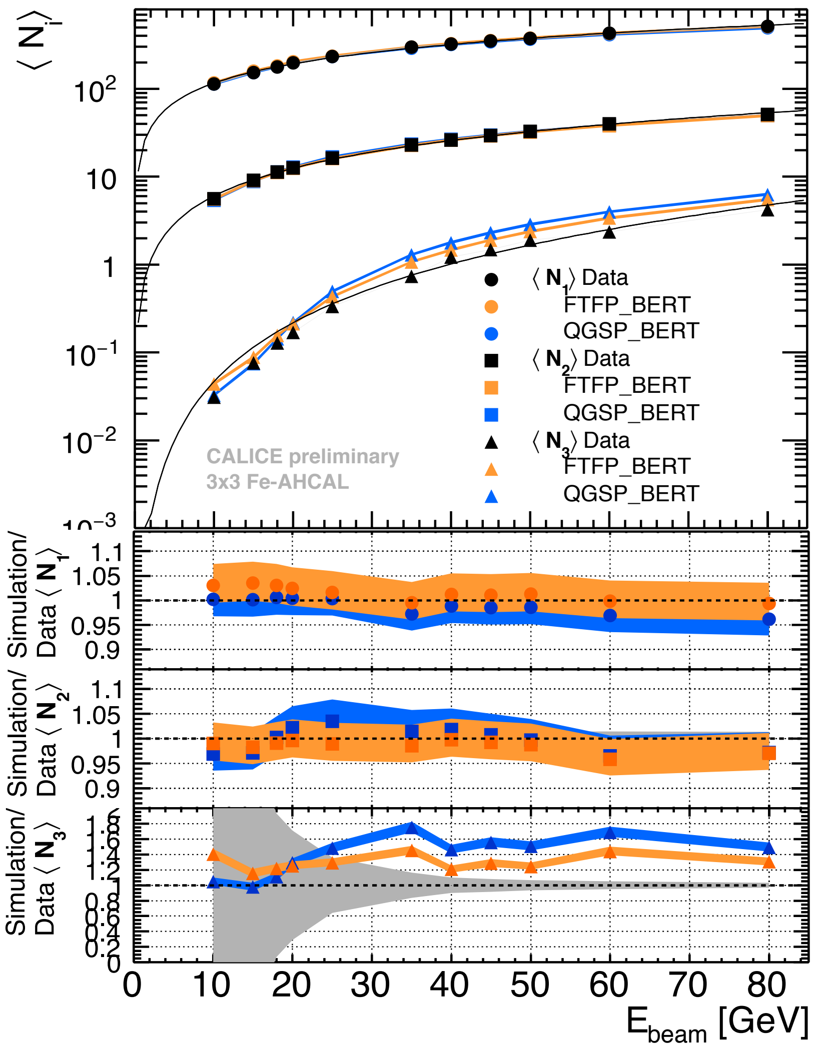
  N_3: t_3 < hits

$$N_{hits} = N_1 + N_2 + N_3$$

→ Weights determined for 3 classes of hits

$$E_{rec,SD} = \sum_{j=1}^{3} \alpha_j \left(N_{hits}\right) \cdot N_j$$

$$\chi^2 = \sum_{i=1}^{N} \frac{\left(E^i_{beam} - E^i_{rec,SD}\right)^2}{E^i_{beam}}$$

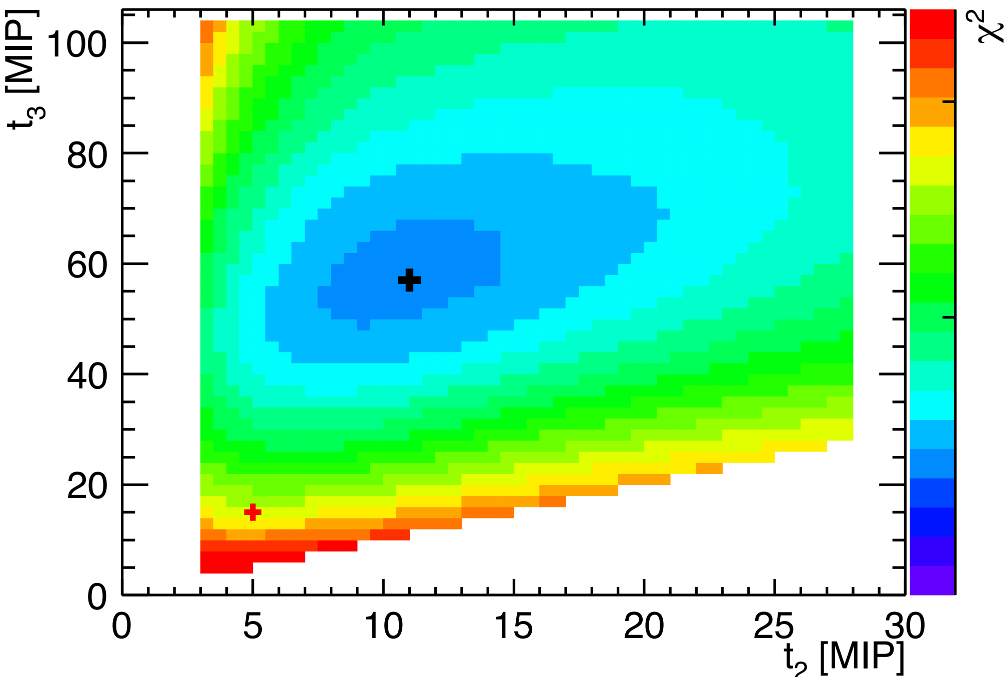


→ Idea for optimisation: χ^2 value gives estimate of reconstruction accuracy

Optimisation of Semi-Digital Thresholds

- For 3x3 AHCAL
  - Optimisation procedure done with data
  - Scan of threshold range: t_2 in 0.5MIP and t_3 in 1MIP steps, lowest threshold fixed to

$$t_1 = 0.5 \text{ MIP}$$



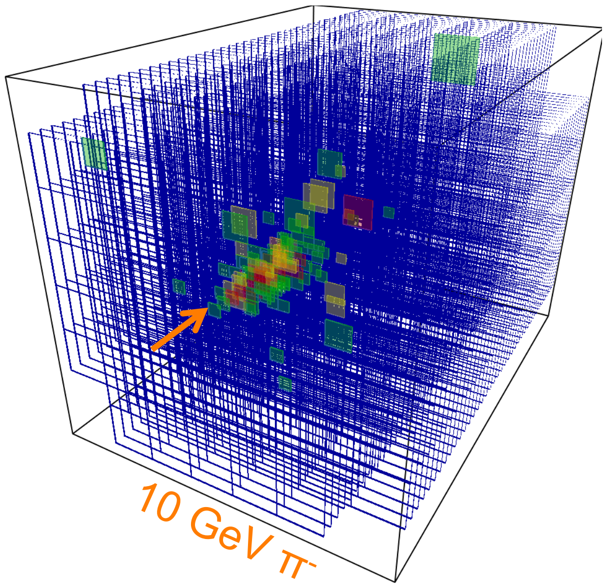
- Minimum chi2 value (black cross) found at

$$t_1 = 0.5 MIP$$
$$t_2 = 10.5 MIP$$
$$t_3 = 57 MIP$$

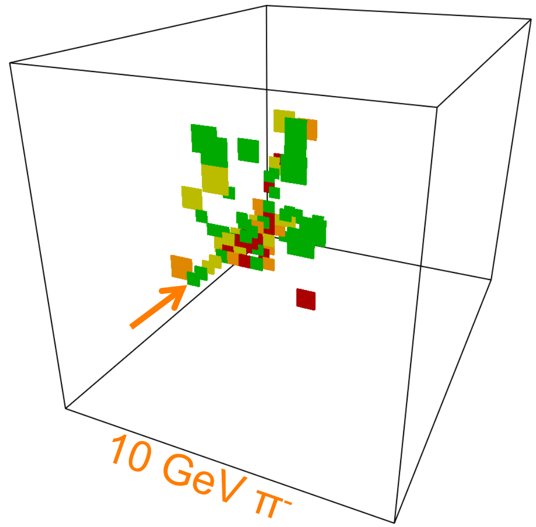
- Red cross marks the values previously used, following the MICROMEGAS SDHCAL thresholds

Impact of Granularity

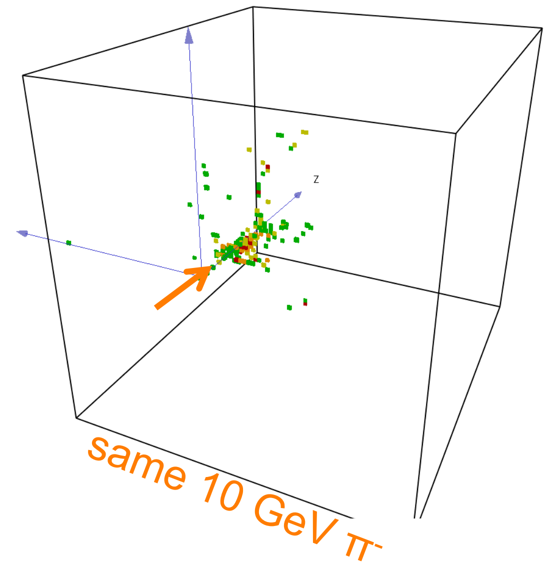
Data: min. 3x3cm^2 tiles



Simulation: min. 3x3cm^2 tiles



Simulation: 1x1cm^2 tiles



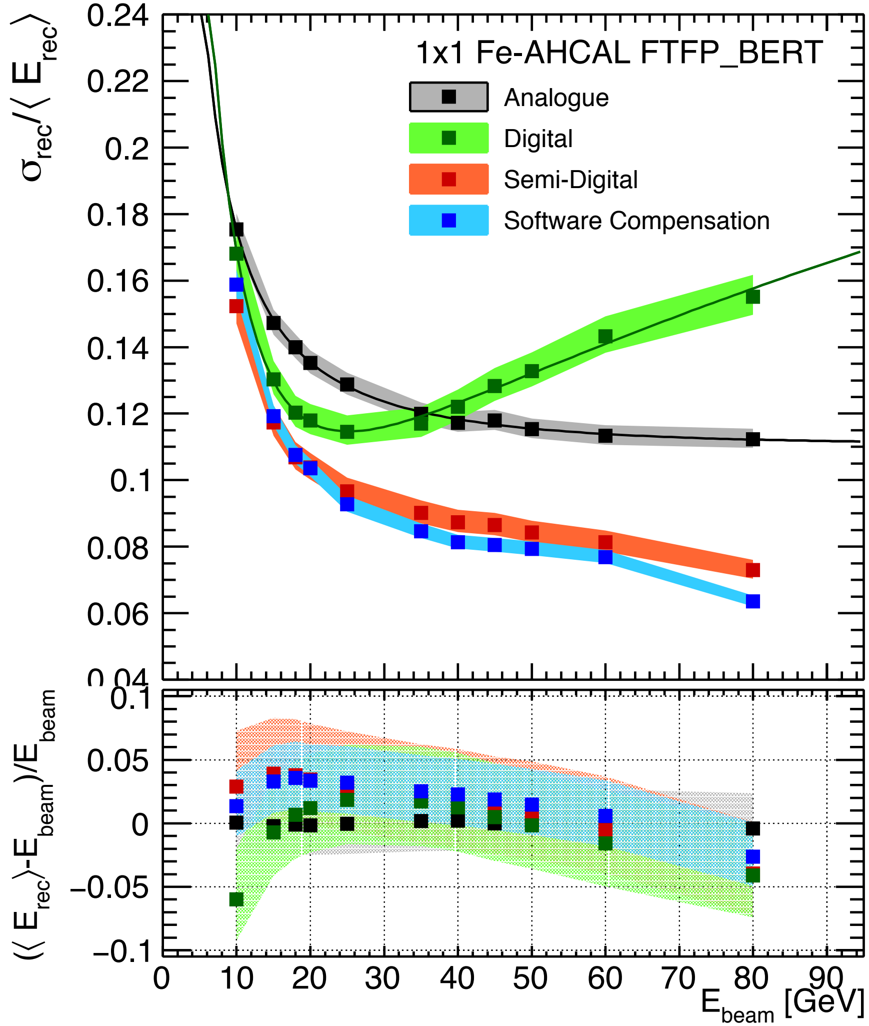
1m^3 Analogue Scintillator-Steel HCAL physics prototype, **simulation (Geant4 9.6 based) fits data**

> Granularity is altered in simulation to 1x1cm^2

Shown at Kyushu: Energy Resolution of 1x1 AHCAL MC

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

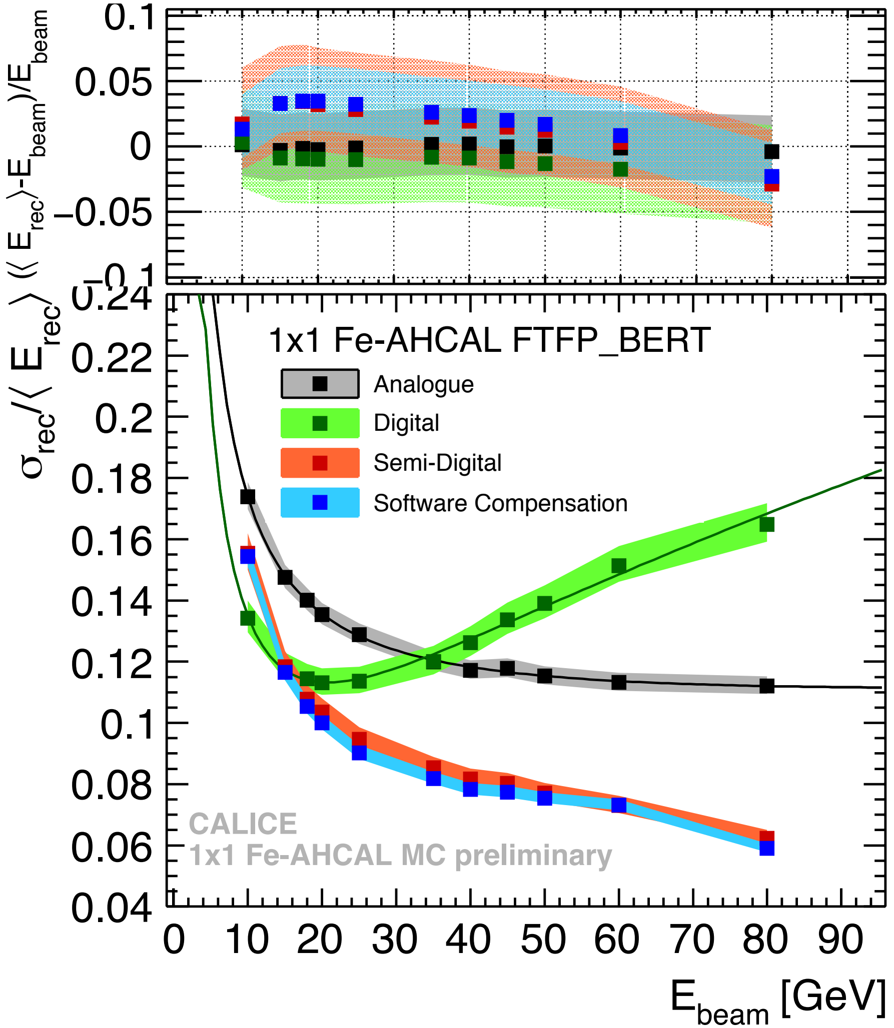
- **Analogue**
  - 3x3→1x1 no change!
- **Digital**
  - Better resolution than Analogue reconstruction for energies below 30 GeV due to Landau fluctuations?
- **Semi-Digital**
  - No threshold optimisation!



Shown at CALOR: Energy Resolution of 1x1 AHCAL MC

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

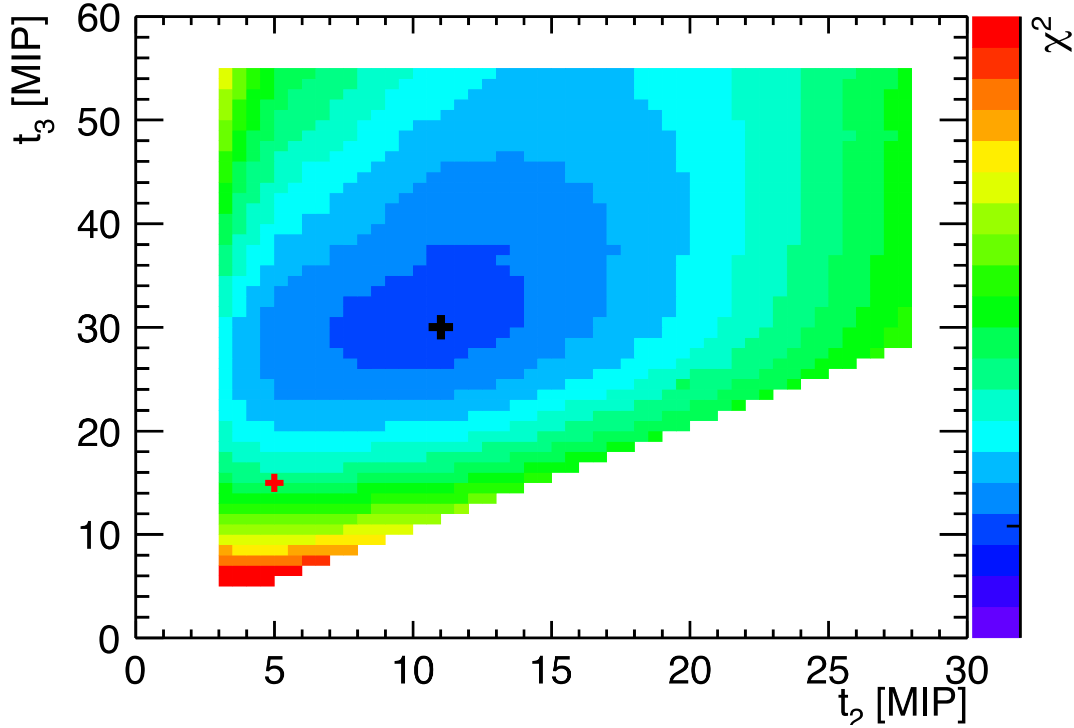
- **Analogue**
  - 3x3→1x1 no change!
- **Digital**
  - Better resolution than Analogue reconstruction for energies below 30 GeV due to suppression of Landau fluctuations?
- **Semi-Digital achieves Software Compensation resolution**



Optimisation of Semi-Digital Thresholds 1x1cm² AHCAL

- For 1x1cm² AHCAL
  - Optimisation procedure done with MC
  - Scan of threshold range: t_2 in 0.5MIP and t_3 in 1MIP steps, lowest threshold fixed to

$$t_1 = 0.3 \text{ MIP}$$



- Minimum chi2 value (black cross) found at

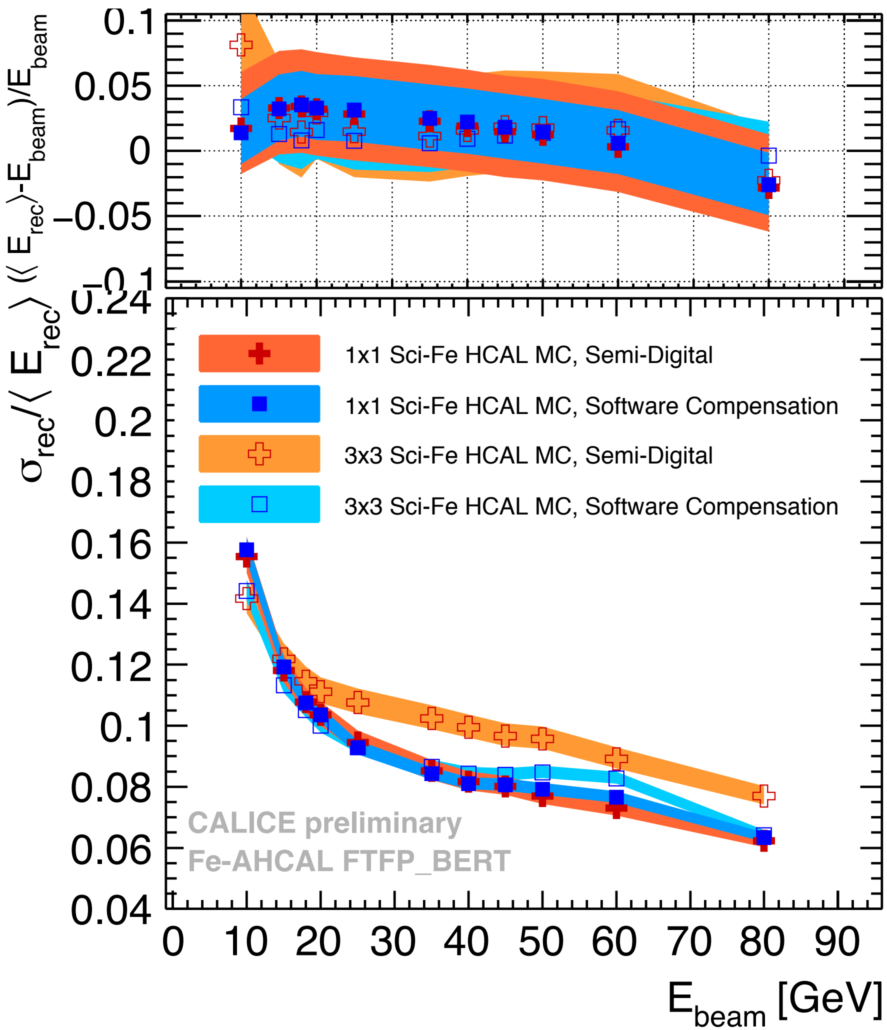
$$t_1 = 0.3MIP$$
$$t_2 = 10.5MIP$$
$$t_3 = 30MIP$$

- Red cross marks the values previously used, following the MICROMEGAS SDHCAL thresholds → closer to minimum than in 3x3cm²

Comparison of 1x1 & 3x3 AHCAL Simulation

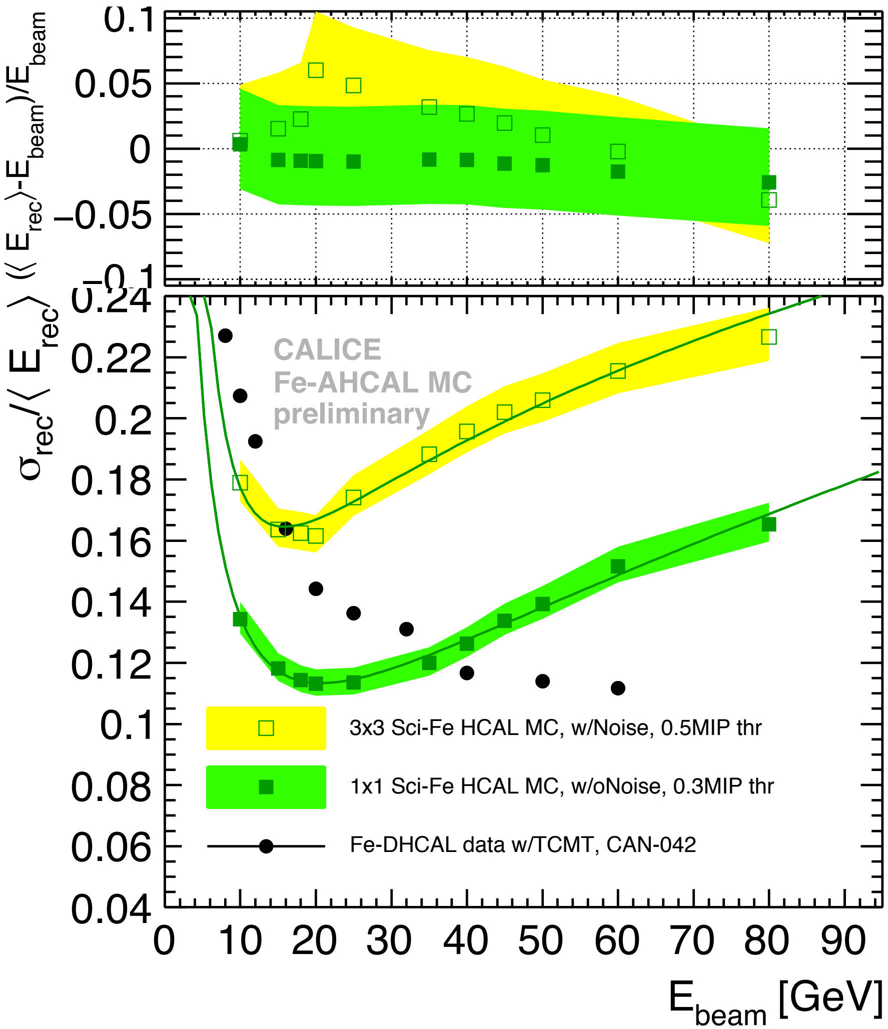
- Same reconstruction method
- Semi-Digital energy reconstruction shows granularity dependence
- Software Compensation doesn't improve with higher granularity

- 1x1 Semi-Digital equivalent to 3x3 Software Compensation



Comparison of 1x1 AHCAL MC & DHCAL Data

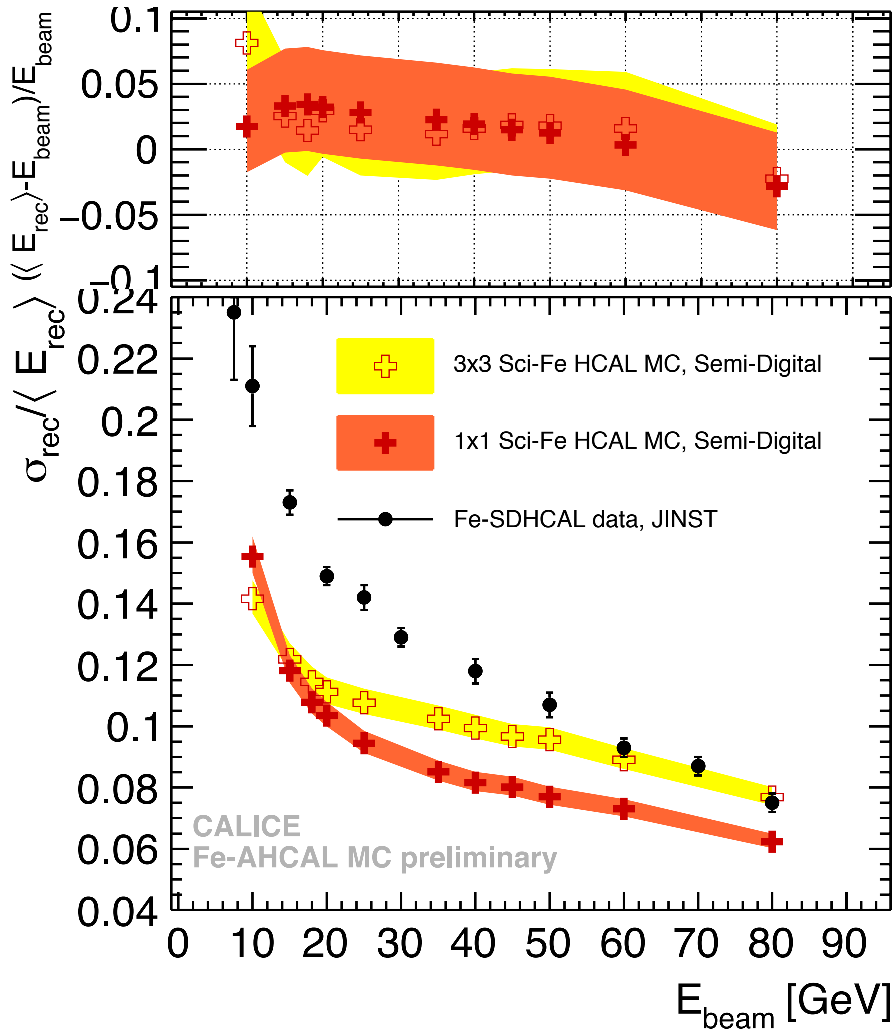
- Same reconstruction method
- FTFP_BERT Simulation for 3x3 and 1x1 AHCAL
- Saturation in DHCAL data reduced by fitting method and included TCMT
- Hint that higher efficiency of Scintillator tiles improves digital reconstruction for low energies



Comparison of 1x1 AHCAL MC & SDHCAL Data

- Same reconstruction method
- FTFP_BERT Simulation for 3x3 and 1x1 AHCAL
- SDHCAL data taken with 10 more active layers!
  - Nevertheless 1x1 AHCAL MC better

- Hint that higher efficiency of Scintillator tiles improves semi-digital reconstruction for low energies



Conclusions

- For analogue readout $3x3cm^2$ cell size sufficient
- For $1x1cm^2$ AHCAL semi-digital readout sufficient

→ Understood: Readout and Granularity

→ Need to understand: Scintillator versus RPC gas

- Impact on Particle Flow algorithm need to be verified

Thank you!

BACKUP: Energy Reconstruction Schemes

- Compare SC and SD weights:

$$E_{rec,SC} = \sum_{j=1}^{N_{hits}} \omega\left(e_j, E_{sum}\right) \cdot e_j$$

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

- ω and α_i depend on E_{sum} and N_{hits}
- ω weights energy of hits, α_i weights the number

$$\sum_{i=1}^{3} N_i = \sum_{j=1}^{N_{hits}} e_j \Big/ e_j$$

- Forced $1/e_j$ dependence shows nice agreement with SC findings