

DAS HCAL



Eine Partnerschaft der
Universität Hamburg und DESY

Coralie Neubüser, [Felix Sefkow](#)
Linear Collider Workshop
Belgrade, 7.10.14



Digital, Analogue and Semi-digital Energy Reconstruction in the AHCAL

Fe-AHCAL test beam CERN 2007



[Coralie Neubüser, Felix Sefkow](#)
Linear Collider Workshop
Belgrade, 7.10.14

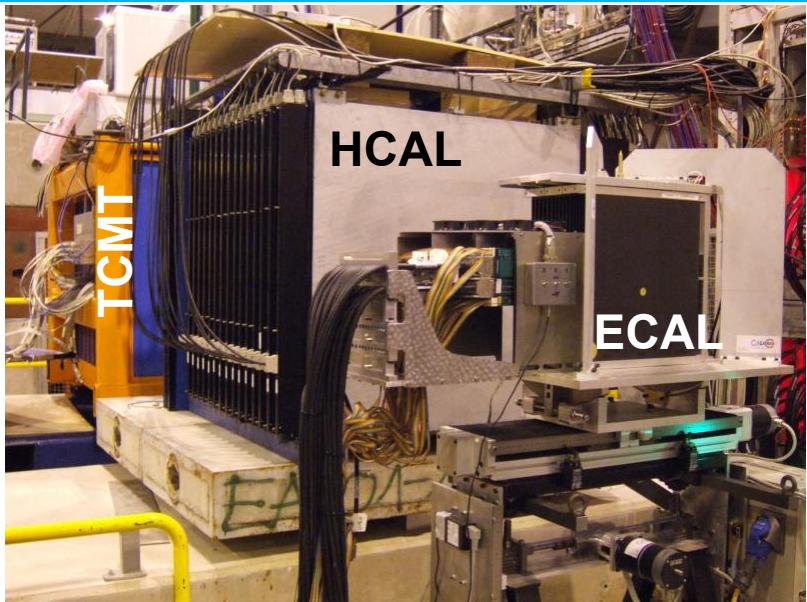


Outline and idea

- Data selection
- Analogue, digital and semi-digital reconstruction modes
- Response and resolution
- Further steps
 - With analogue read-out, (semi-) digital reconstruction is possible, too
 - Understand impact on energy resolution
 - AHCAL granularity not optimised for (semi-) digital methods
 - Validate simulation for the study of finer segmentations
 - Study trade-offs between spatial and energy information

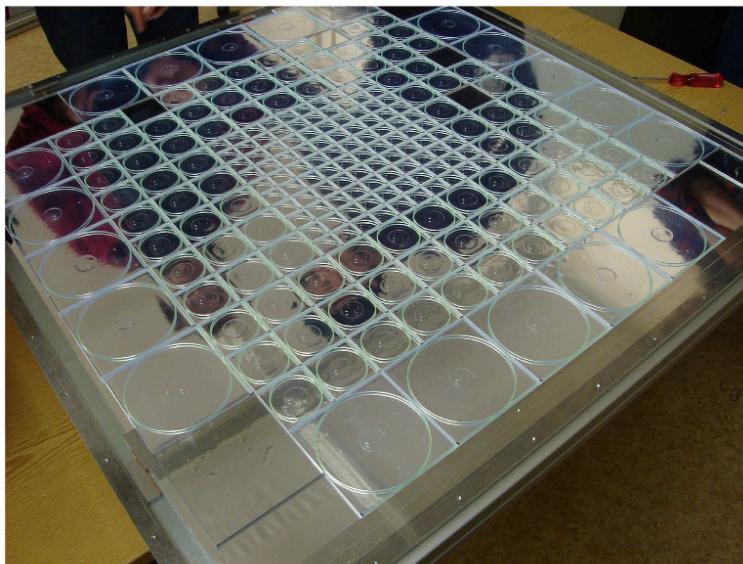


CALICE test beam 2007 at CERN



- 38 layers Scintillator tile Analog HCAL (12bit readout)
- Granularity: 12x12, 6x6 and 3x3cm² tiles/cells
- Read out of scintillation light by SiPMs

- SPS at CERN 2007 (10-80GeV $\pi/e/\mu$)
- Silicon-Electromagnetic Calorimeter (Si-ECAL) + **1m³ Analog Hadronic Calorimeter (Fe-AHCAL)** + Tail Catcher/Muon Tracker (TCMT)
- Fe-absorber ~2cm



C. Adloff et al., "Construction and commissioning of the CALICE analog hadron calorimeter prototype", JINST, vol. 5, p. P05004, 2010.

π^- runs 10-80GeV: Event Selection

- > Test beam is a composition of different particle types

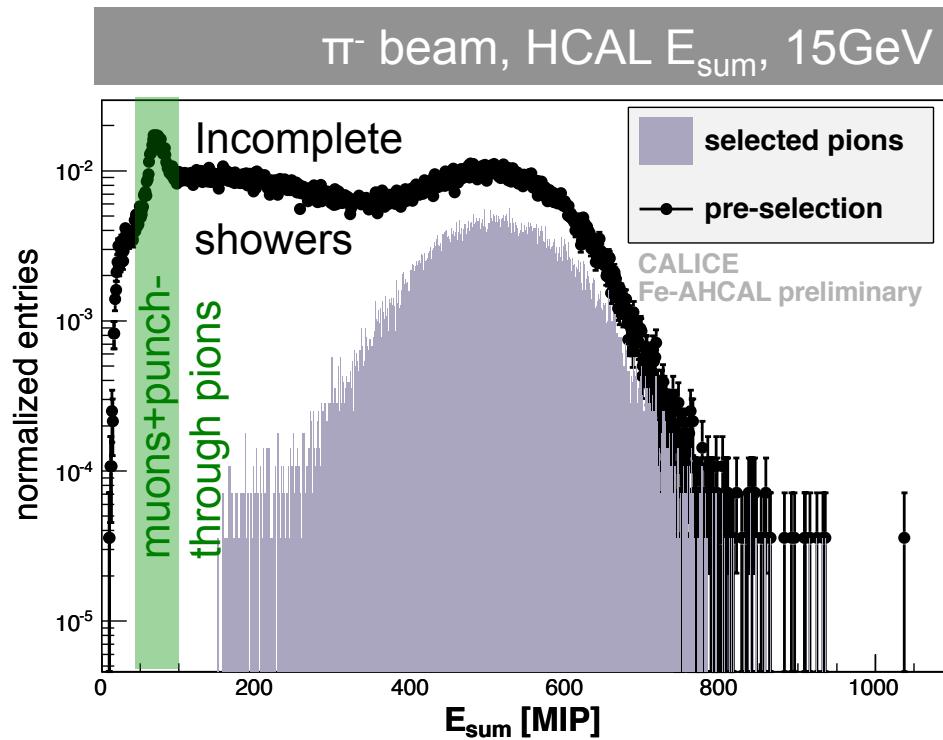
Particle identification

- Muons (e.g. decayed pions)
- Other hadrons (e.g. Protons)

Additional selection

- Shower start in first 5 HCAL layers to study full shower in AHCAL
- Require track in ECAL

Pre-selection: only Cherenkov Counters



- > Event selection follows „*Hadronic energy resolution of a highly granular scintillator-steel hadron calorimeter using software compensation techniques*“ 2012_JINST_7_P09017: **29 Runs, 11 Energies**

π^- runs 10-80GeV: Event Selection

- > Test beam is a composition of different particle types

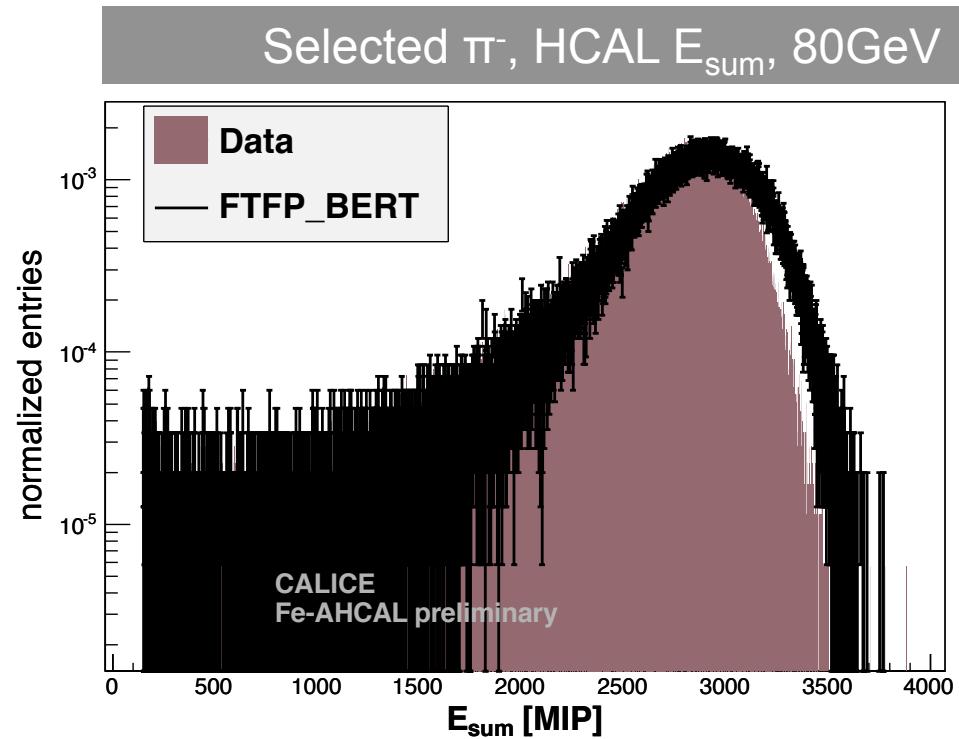
Particle identification

- Muons (e.g. decayed pions)
- Other hadrons (e.g. Protons)

Additional selection

- Shower start in first 5 HCAL layers to study full shower in AHCAL
- Require track in ECAL

Pre-selection: only Cherenkov Counters



- > MC sample with GEANT 4 version 9.6, physics list FTFP_BERT
- > Same runs like data with corresponding noise files
- > FTFP_BERT overestimates HCAL response **for high energies**

π^- runs 10-80GeV: Event Selection

- > Test beam is a composition of different particle types

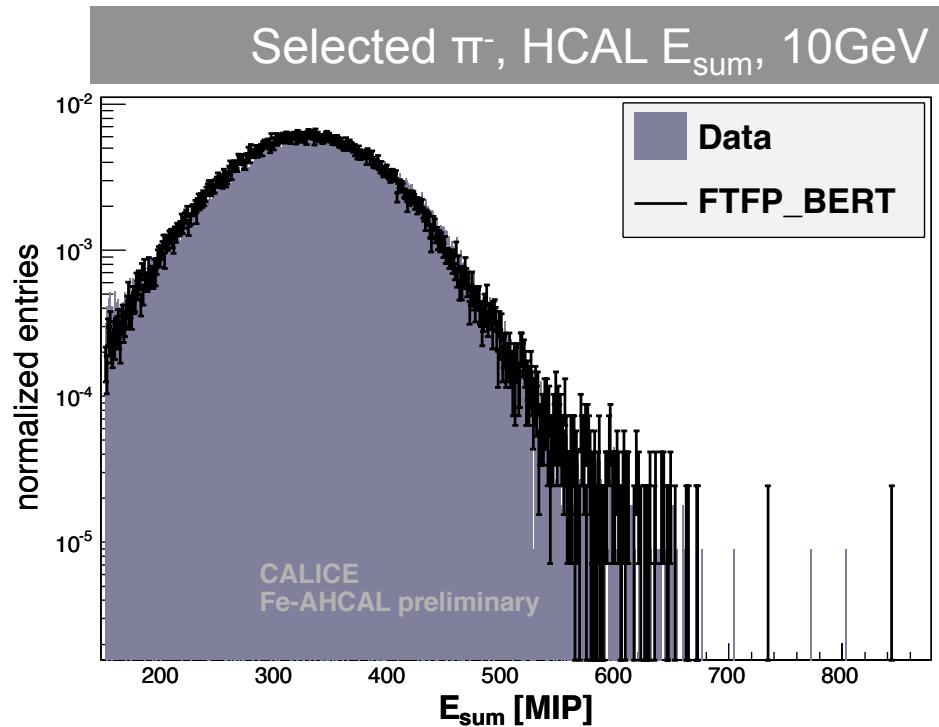
Particle identification

- Muons (e.g. decayed pions)
- Other hadrons (e.g. Kaons)

Additional selection

- Shower start in first 5 HCAL layers to study full shower in AHCAL
- Require track in ECAL

Pre-selection: only Cherenkov Counters

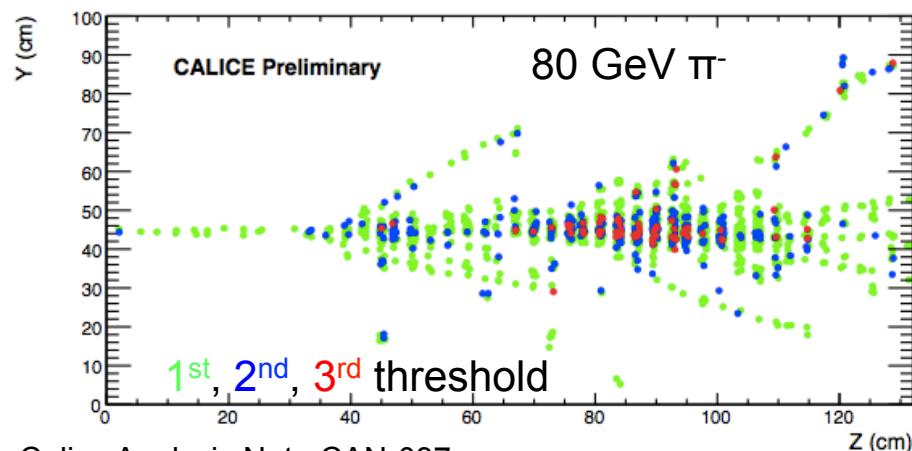
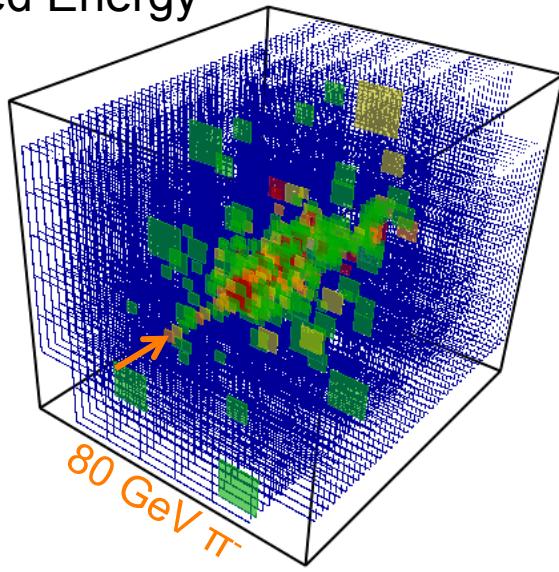


- > MC sample with GEANT 4 version 9.6, physics list FTFP_BERT
- > Same runs like data with corresponding noise files
- > FTFP_BERT describes HCAL response for energies below 45GeV

CALICE Hadronic Calorimeters (3 approaches)

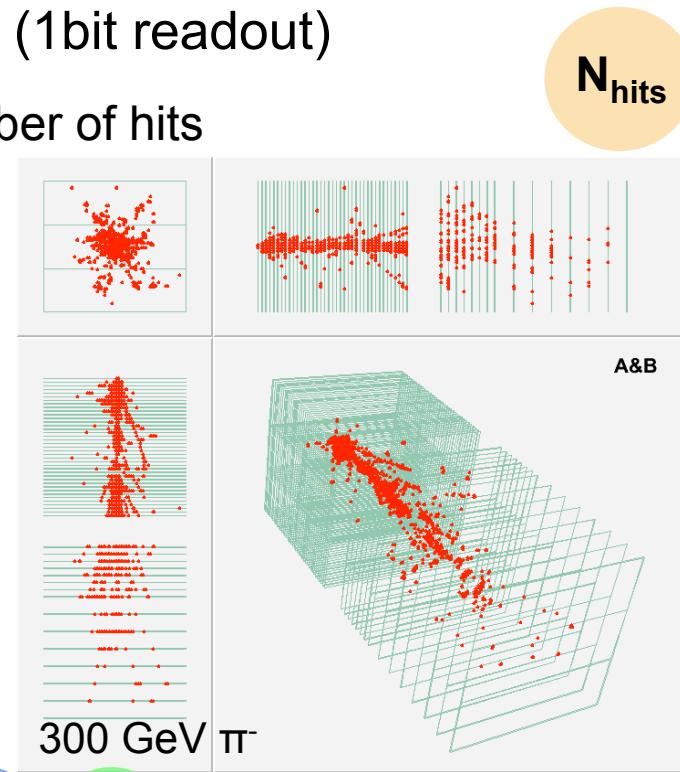
Analogue (12bit readout)

- Deposited Energy



Digital (1bit readout)

- Number of hits



N_3 N_2 N_1

Semi-digital (2bit readout)

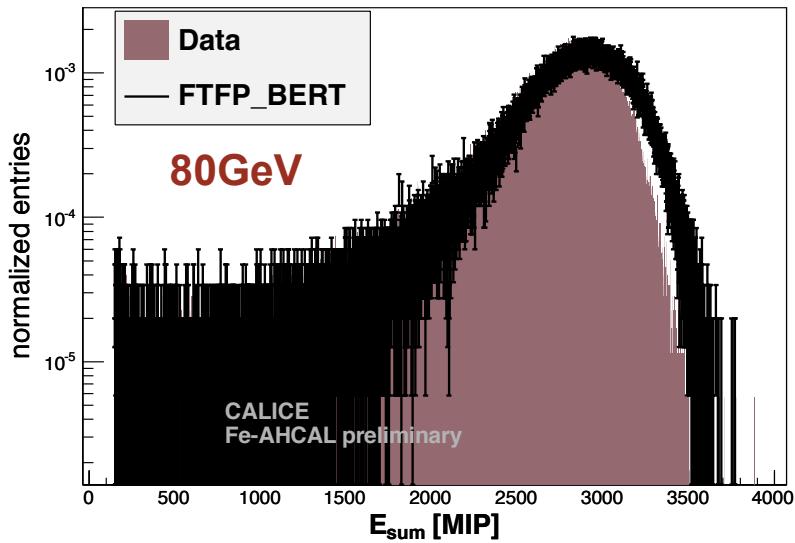
- Number of hits above each of 3 thresholds



Pion responses in AHCAL

Analogue (12bit readout)

- Deposited Energy

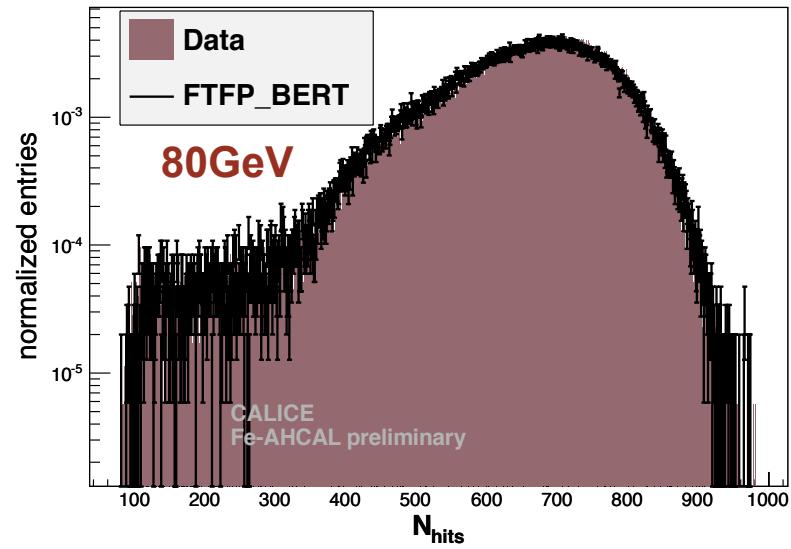


"Standardised" mean extraction procedure:

1. Gaussian pre-fit
2. Novosibirsk fit within $\mu \pm 3\sigma$ of Gaussian ($\chi^2 < 3$)
3. Novosibirsk parameters for filling histogram randomly from 0 to 3σ
4. Mean & RMS of histogram

Digital (1bit readout)

- Number of hits



$$N_3 + N_2 + N_1$$

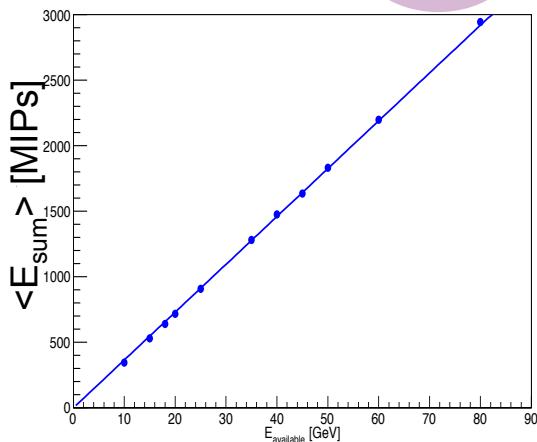
Semi-digital (2bit readout)

- Number of hits above each of 3 thresholds

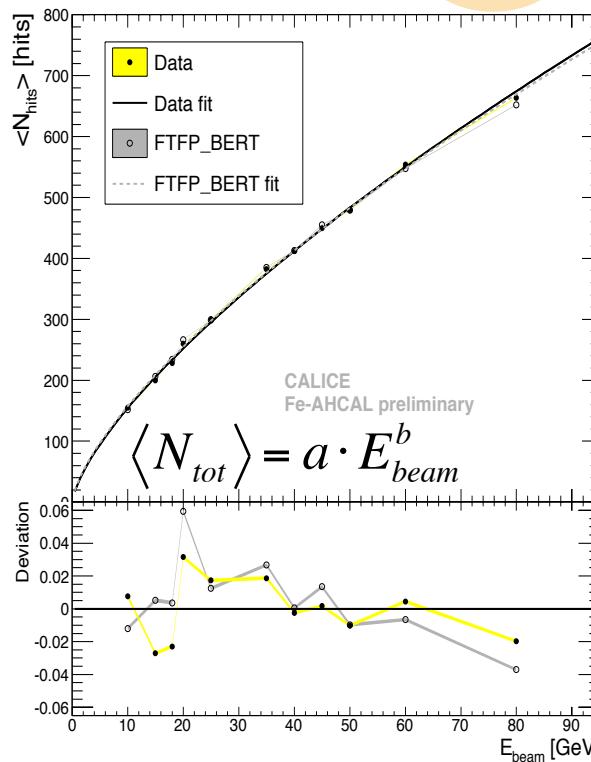


Mean pion responses in AHCAL

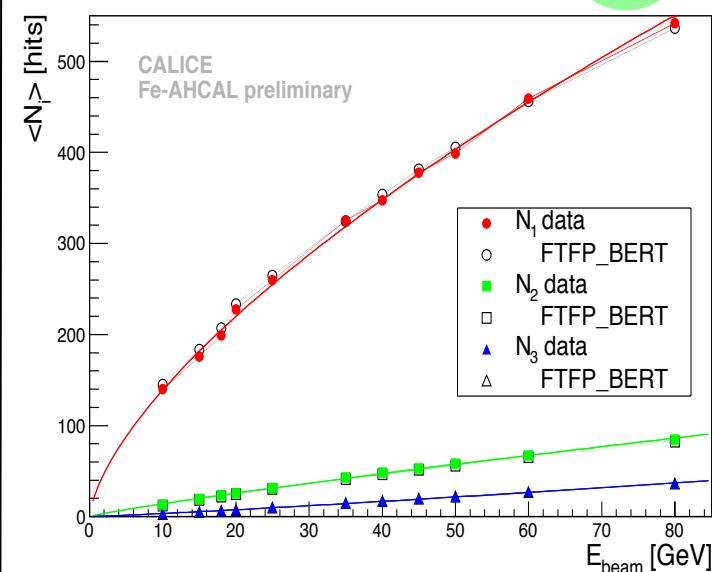
Analogue $\langle E_{\text{sum}} \rangle$



Digital $\langle N_{\text{hits}} \rangle$



Semi-Digital $\langle N_i \rangle$



Linear correlation to beam energy

- ADC counts → Minimum Ionizing Particles (calibration with muons)
- Energy reconstruction with constant conversion factor
- Linear to good approximation since e/π close to 1

Non-linear response

- Multi-traversing particles & pad size
- Requires more sophisticated reconstruction method to linearise

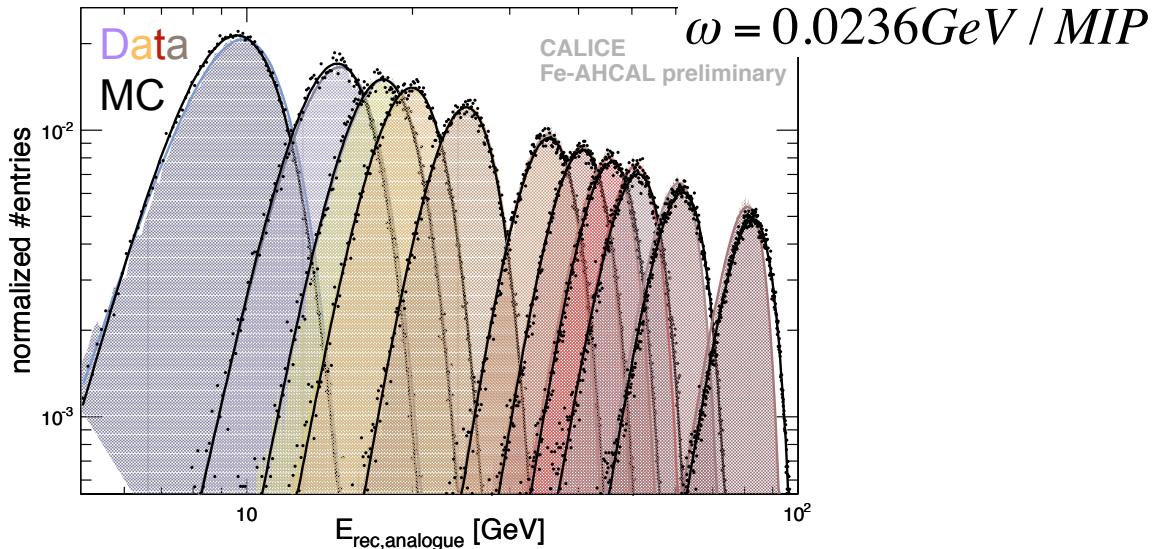
N_i = number of hits with

- N_1 : $0.5\text{MIP} < E_{\text{hit}} < 5\text{MIP}$
- N_2 : $5\text{MIP} < E_{\text{hit}} < 15\text{MIP}$
- N_3 : $15\text{MIP} < E_{\text{hit}}$

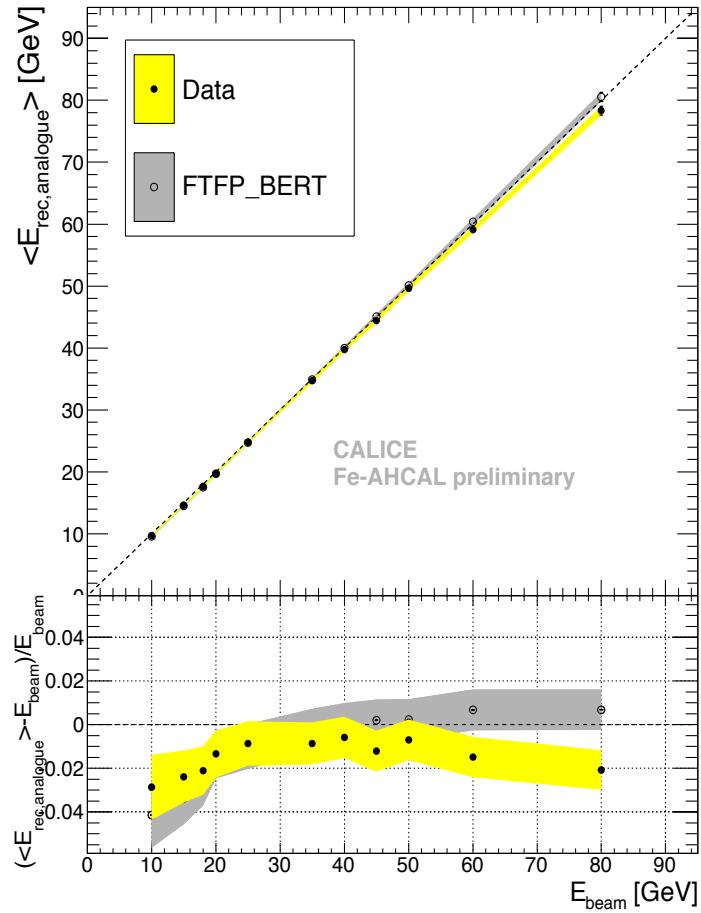
Analogue energy reconstruction

$$E_{rec,analog} = 0.3805 GeV + \frac{e}{\pi} \cdot \omega \cdot E_{sum}$$

$$\frac{e}{\pi} = 1.19$$



- Mean deposited track energy in ECAL 0.3805GeV
- Conversion factor ω taken from positron runs
- Non-compensation (response for electrons 1.19 times higher than for pions)
- Non-linearity less than 5%
- Good agreement between data and MC



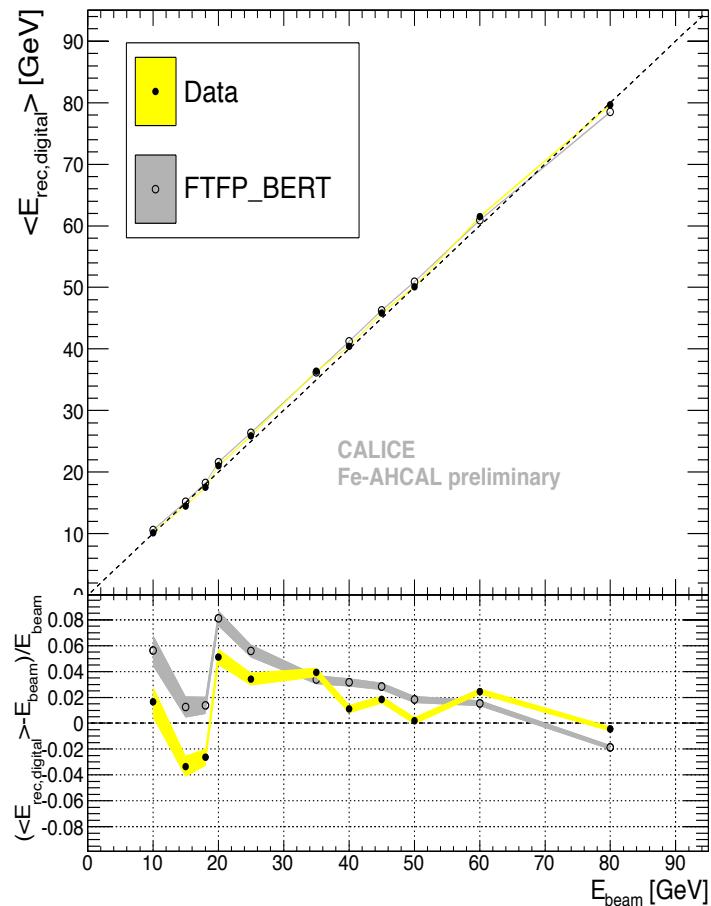
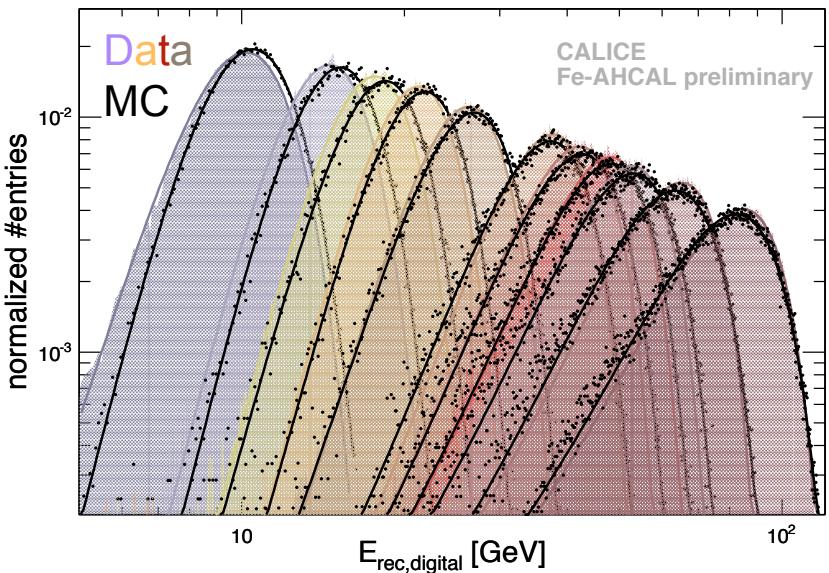
Digital energy reconstruction

From the data fit:

$$E_{rec,digital} = b \sqrt{\frac{N_{tot}}{a}}$$
$$a = 30.06 GeV^{-b}$$
$$b = 0.71$$

and assuming

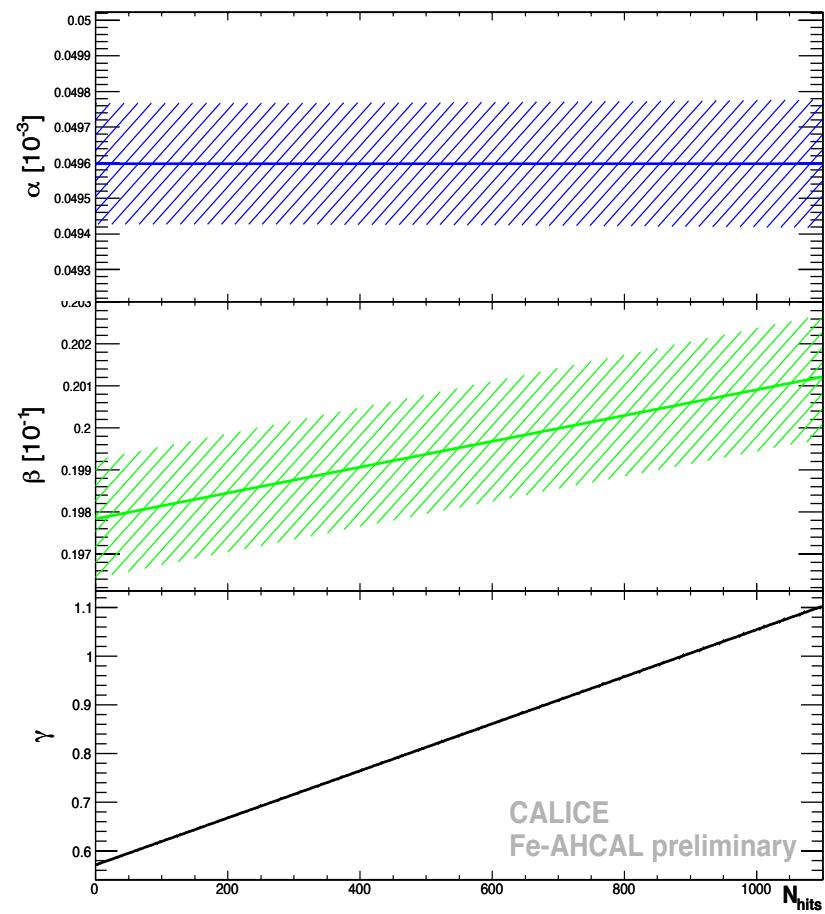
$$E_{beam} = E_{rec,digital}$$



- Tail on left hand side of distributions due to multiple particles traversing same cell
- Non-linearity less than 8% after correction
- Agreement between data and MC better with increasing energies

Semi-digital energy reconstruction

$$E_{rec,3thr} = \alpha N_1 + \beta N_2 + \gamma N_3$$



- Weighting hits depending on energy content

$N_1 : 0.5MIP < E_{hit} < 5MIP$

$N_2 : 5MIP < E_{hit} < 15MIP$

$N_3 : E_{hit} > 15MIP$

- α, β and γ assumed to be quadratic polynomials of N_{hits}

$$\chi^2 = \sum_{i=1}^N \frac{(E_{beam}^i - E_{rec,semi-digital}^i)^2}{E_{beam}^i}$$

- From minimisation: α, β and γ show none or linear dependence on N_{hits}
- Results in bad linearity, additional linearisation step needed

Semi-digital energy reconstruction

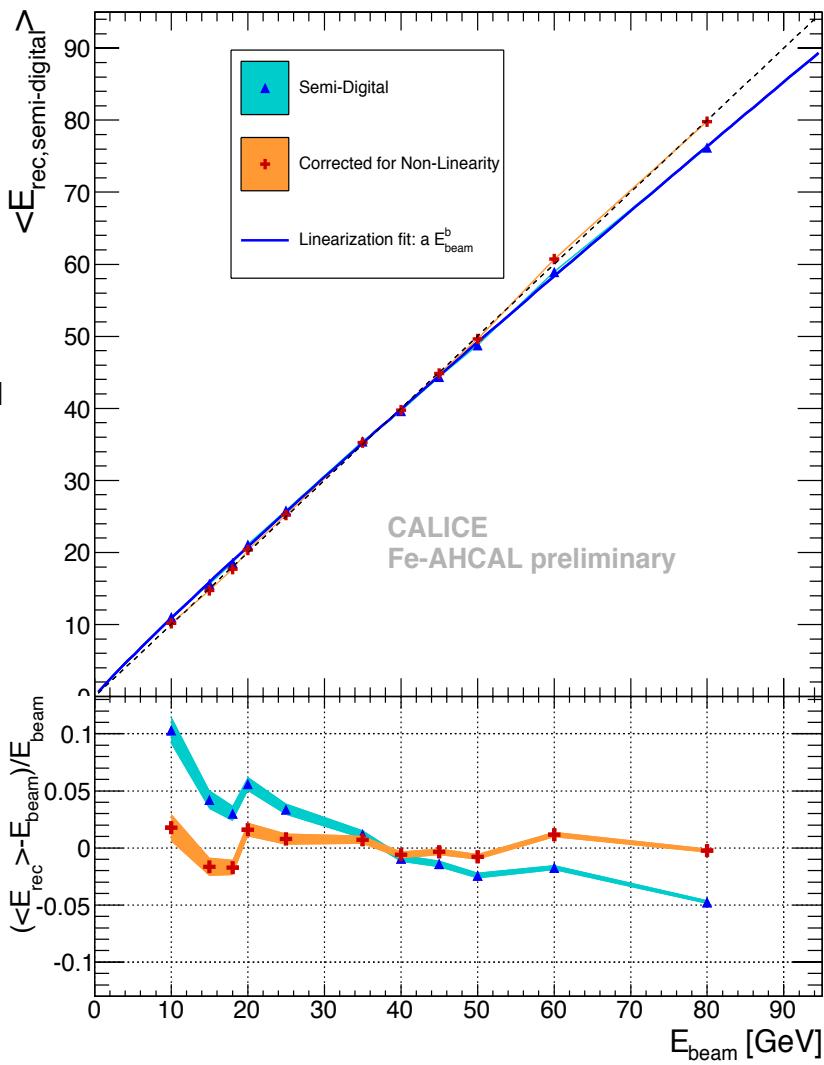
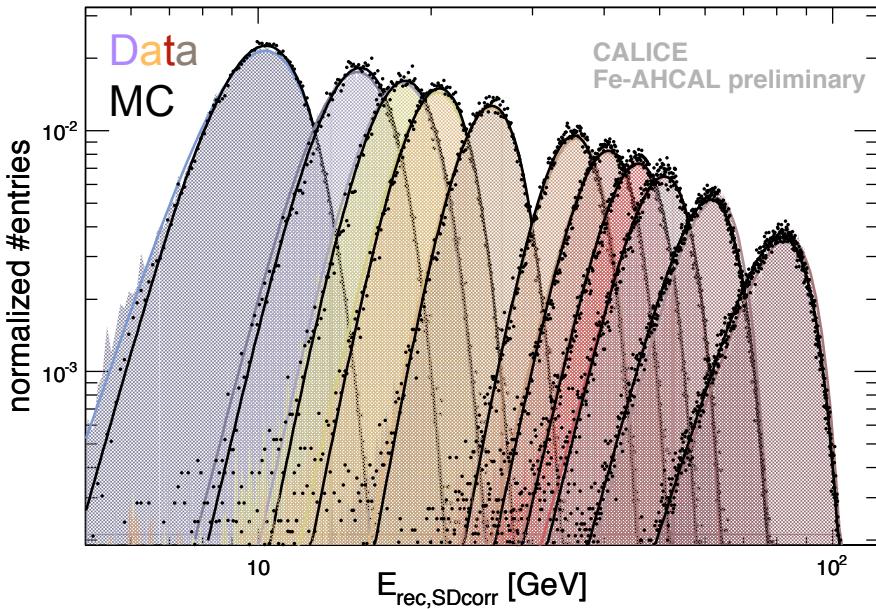
- Linearisation step similar to digital reconstruction

$$a = 1.25 \text{ GeV}^b$$

$$b = 0.94$$

$$E_{rec,SDcorr} = \sqrt[b]{\frac{E_{rec,semi-digital}}{a}}$$

- Reduced tail on the left, compared to $E_{rec,digital}$
- Non-linearity less than 3% after correction



Energy Resolution

$$\frac{\sigma_{rec}}{\langle E_{rec} \rangle} = \frac{a}{\sqrt{E_{beam} [GeV]}} \oplus b \oplus \frac{c}{E_{beam} [GeV]} \oplus d \left(\frac{E_{beam} [GeV]}{100} \right)^e$$

> Analogue:

- Without TCMT, resolution for high energies degrades

> Digital:

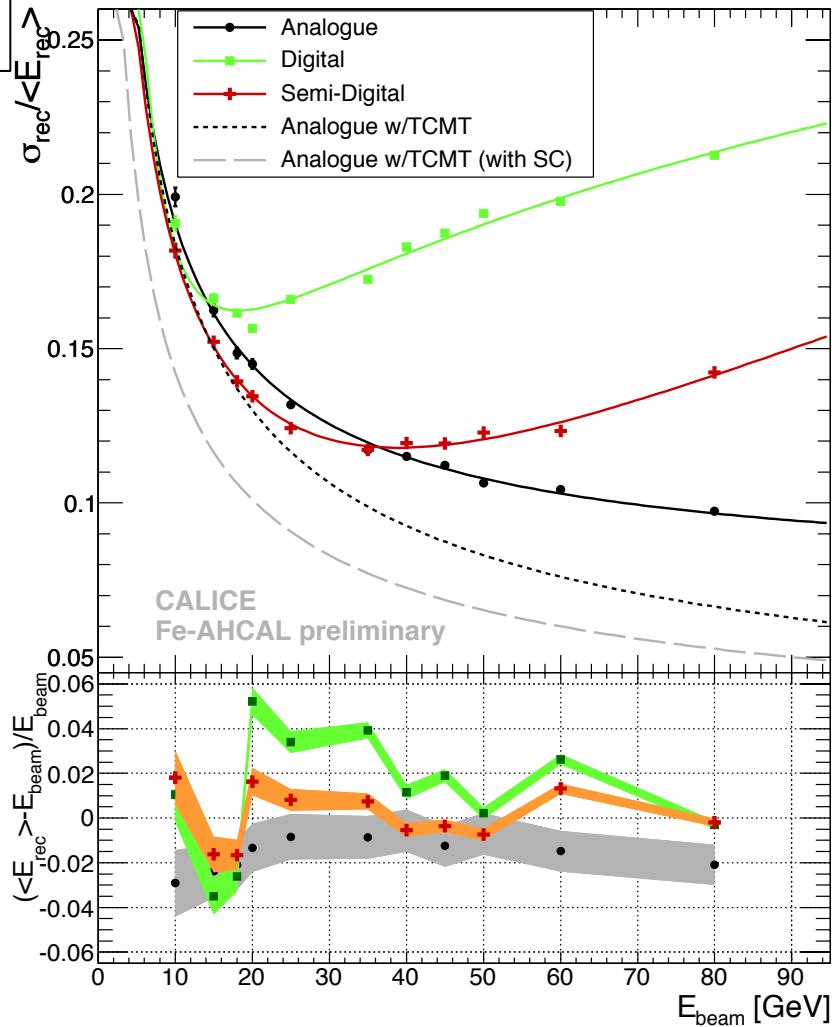
- Steep increase above 20GeV

> Semi-digital:

- Best resolution below 35GeV

> But:

- AHCAL+TCMT, especially with software compensation shows best results
- Semi-digital energy reconstruction uses similar “weighting” method as SC techniques



Conclusion

CALICE Analysis Note CAN-049

<https://twiki.cern.ch/twiki/bin/view/CALICE/CaliceAnalysisNotes>

CALICE Analysis Note CAN-049
May, 2014

Analogue, Digital and Semi-Digital Energy Reconstruction in the CALICE AHCAL

The CALICE Collaboration

Abstract

In this note, different energy reconstruction methods for the Analogue Hadronic Calorimeter (AHCAL) are compared. These methods were developed for the analogue, digital and semi-digital CALICE Hadronic Calorimeter physics prototypes and were used in analyses of data taken at various test beams.

The analogue data can also provide digital information, thus the advantages and dis-

advantages of different energy reconstruction procedures can be studied in the same

data sample. In this work this comparison is done by applying these procedures to

AHCAL pion test beam data collected with the 1m^3 physics prototype in 2007 at

CERN. The results are compared to a GEANT4 based simulation.

This note contains preliminary CALICE results, and is for the use of members

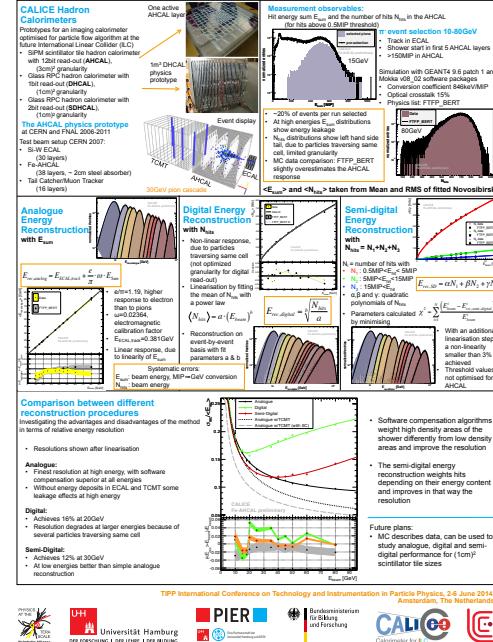
of the CALICE Collaboration and others to whom permission has been given.¹

¹Corresponding authors:
Coralie Neubüser; coralie.neubueser@desy.de
Katja Krüger; katja.krueger@desy.de

Poster + Proceeding for TIPP14 conference

Analogue, Digital and Semi-Digital Energy Reconstruction in the CALICE AHCAL

Coralie Neubüser on behalf of the CALICE Collaboration
DESY, Hamburg, Germany. Email: coralie.neubueser@desy.de <http://www.flc.desy.de/hcal/>



PROCEEDINGS
OF SCIENCE

Analogue, Digital and Semi-Digital Energy Reconstruction in the CALICE AHCAL

Coralie Neubüser, on behalf of the CALICE Collaboration
Deutsches Elektronen Synchrotron (DESY), Hamburg, Germany
E-mail: coralie.neubueser@desy.de

Within the CALICE collaboration different Calorimeter technologies are studied for a future linear collider. These technologies differ in active material, granularity and readout systems. The Analog Hadronic Calorimeter (AHCAL) reads out the signal height of the energy deposition in each calorimeter cell, while the digital HCal detects hits by firing RPC pad sensors above a certain threshold. A 3 bit reader is provided for the semi-digital HCal, which counts hits above three different thresholds per cell. For these three different energy reconstruction procedures are compared. These results also provide digital information, thus the advantages and disadvantages of different energy reconstruction procedures can be studied.

In this work this comparison is done by applying these procedures to AHCAL beam test data, collected with the 1m^3 physics prototype at CERN, and simulated data, generated with GEANT4.

Technology and Instrumentation in Particle Physics 2014,
5-6 June, 2014
Amsterdam, the Netherlands

*Speaker.

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike License. <http://pos.sissa.it/>



Outlook

NEXT STEPS:

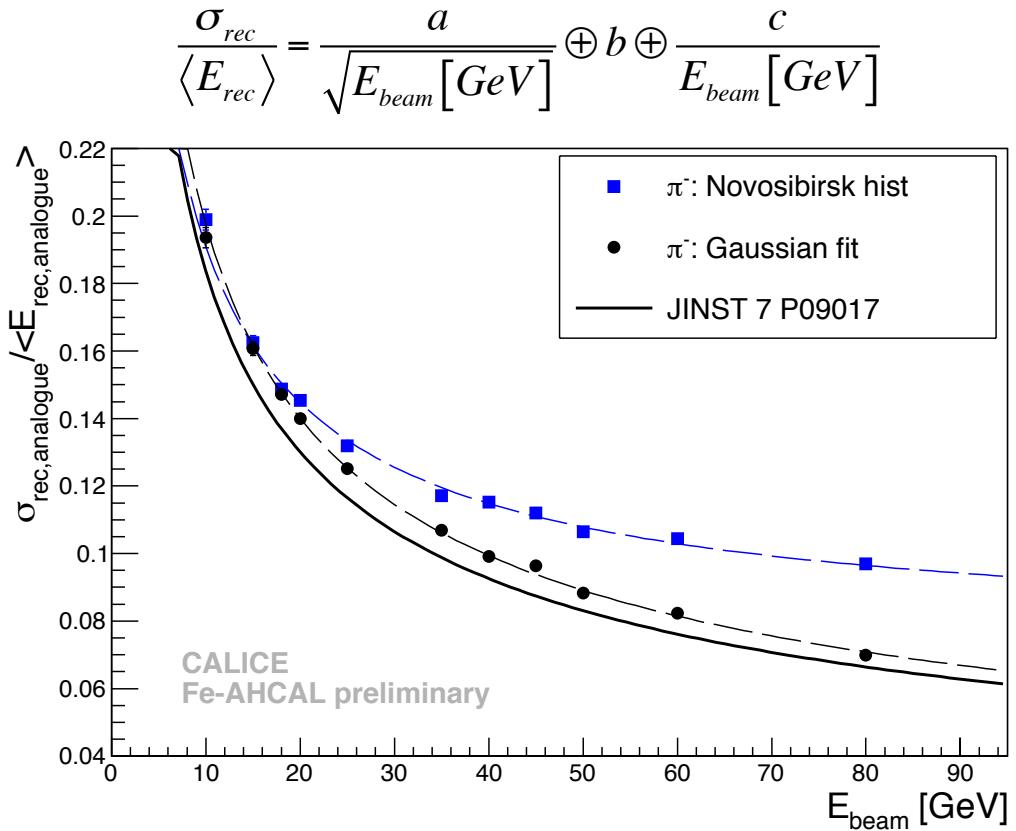
- Optimise semi-digital thresholds, motivated by shower composition
- Reconstruction procedure study on AHCAL MC data with DHCAL
(1x1)cm² cell size, optimised for digital reconstruction
- Comparison to Fe-DHCAL data



Backup

Analogue reconstruction without (detailed) ECAL and TCMT compared to ECAL+AHCAL+TCMT analysis from “Software Compensation”-paper

- 0.5% (in absolute values) above "paper"-values
- Fitting method including tail show expected increase with increasing energy



Backup

Run list & event selection

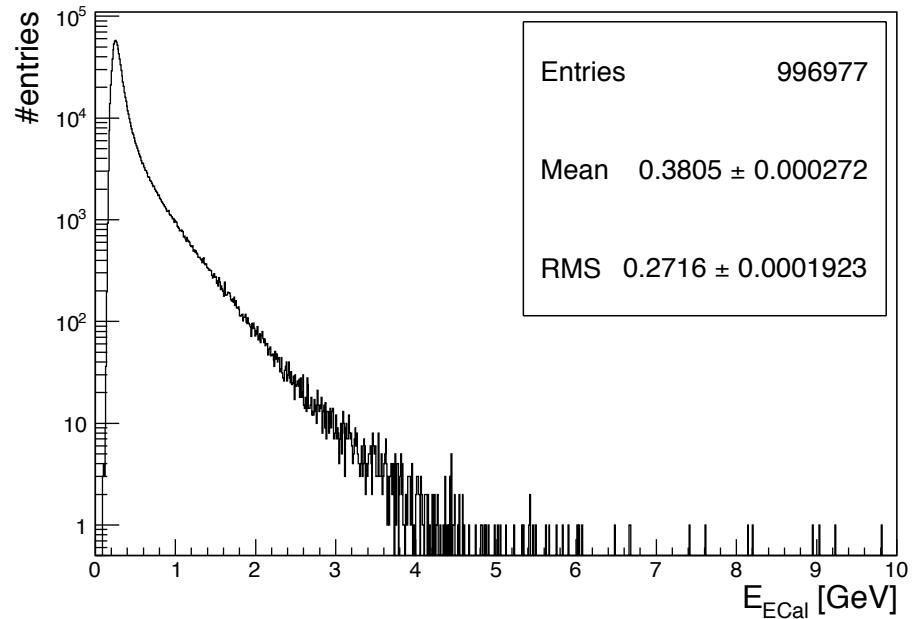
- ~20% of all event selected from data and MC

run number	beam energy [GeV]	pre-selection data	selected pions in data	in %	selected pions in MC	in %
330332, 330643, 330777, 330850	10	587,793	111,133	18.9	81,974	20.5
330328	15	140,441	28,024	20.0	21,063	21.1
330327	18	148,516	29,600	19.9	21,040	21.0
330649, 330771	20	379,270	73,942	19.5	41,718	20.9
330325, 330650	25	364,170	72,530	19.9	41,474	20.7
330551, 330960	35	404,309	70,438	17.4	40,868	20.4
330390, 330412, 330560	40	509,168	101,617	20.0	61,394	20.5
330550, 330559, 330961	45	520,600	102,898	19.8	61,181	20.4
330391, 330558	50	384,581	76,855	20.0	41,081	20.5
331556, 331568, 331655, 331664	60	787,208	153,464	19.5	81,565	20.4
330392, 330962, 331554, 331567, 331654	80	898,307	176,476	19.7	100,278	20.1

Backup

ECAL track energy contribution:

- Energy deposits from all selected events
- Deviation from different beam energies max. 10%



Backup

Analogue, Digital and Semi-digital resolutions

