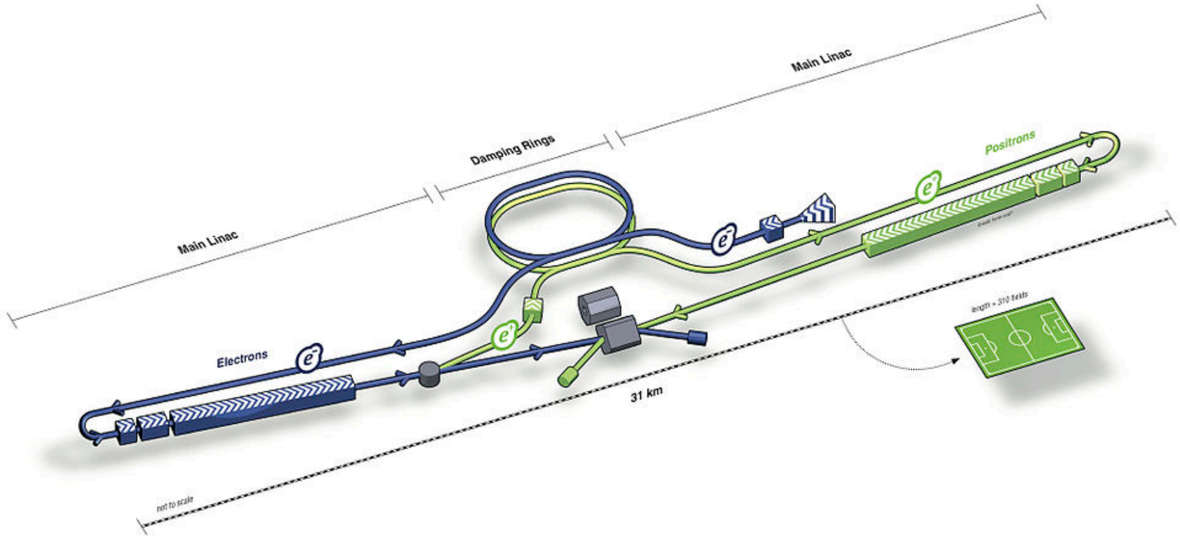
Comparison of two calorimeter concepts for the International Linear Collider (ILC)

Study of different energy reconstruction methods



Coralie Neubüser
DPG Frühjahrestagung
Wuppertal, 11.03.15

Eine Partnerschaft der Universität Hamburg und DESY

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Calorimeters for the ILC

CALICE hadron calorimeters overview

Idea and outline

- With analogue read-out, (semi-) digital energy reconstruction is possible, too
  - Understand impact on energy resolution
- Study trade-offs between spatial and energy information

> Data selection

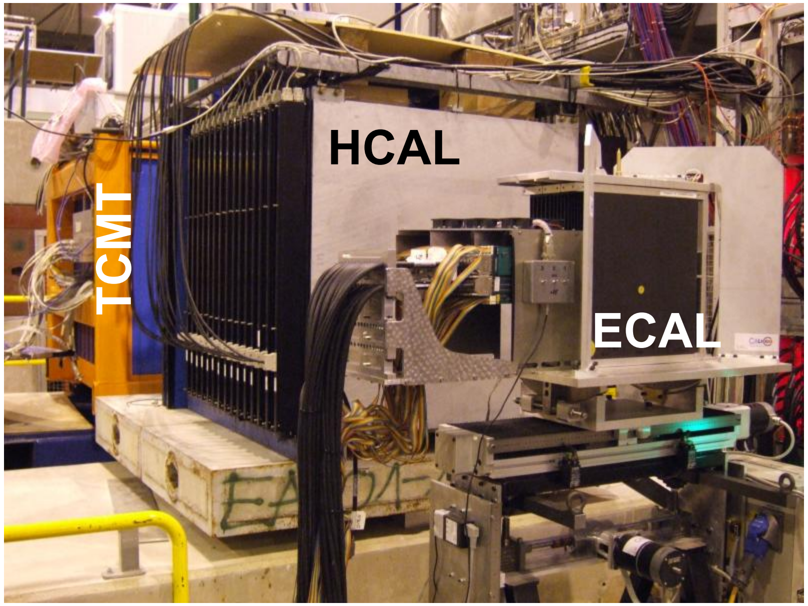
> Analogue, digital and semi-digital reconstruction modes

> Response and resolution

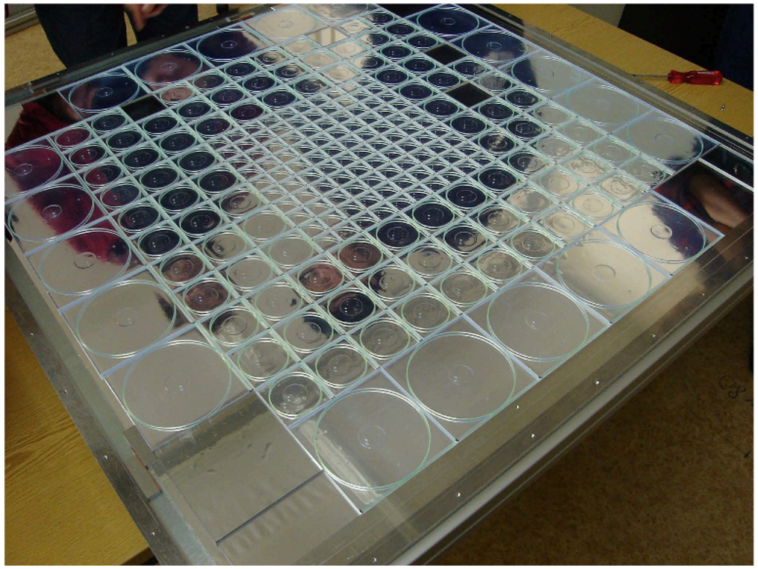
> Further steps

CALICE AHCAL test beam 2007 at CERN

www-flc.desy.de/hcal/cerntestbeam/



- SPS at CERN 2007 (10-80GeV π/e/μ)
- Silicon-Electromagnetic Calorimeter (Si-ECAL) +
  1m^3 Analog Hadronic Calorimeter (Fe-AHCAL) +
  Tail Catcher/Muon Tracker (TCMT)
- Fe-absorber ~2cm

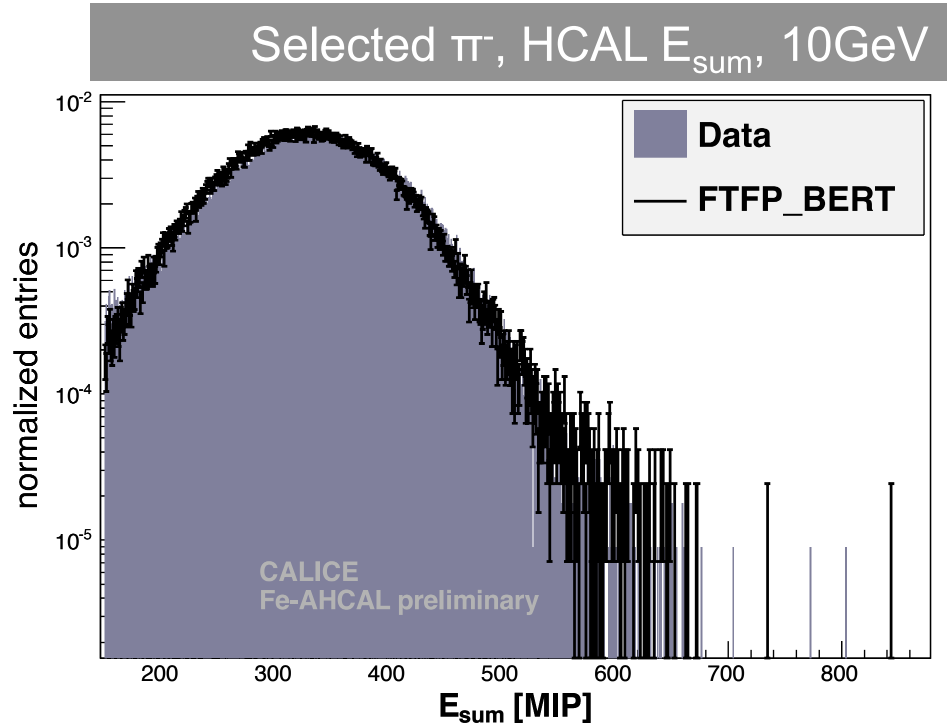


C. Adloff *et al.*, **"Construction and commissioning of the CALICE analog hadron calorimeter prototype"**, *JINST*, vol. 5, p. P05004, 2010.

- 38 layers Scintillator tile Analog HCAL (12bit readout)
- Granularity: 12x12, 6x6 and 3x3cm^2 tiles/cells
- Read out of scintillation light by SiPMs

π^- runs 10-80GeV: Event Selection

> Test beam is a composition of different particle types



> MC sample with GEANT 4 version 9.6, physics list FTFP_BERT

> Same runs like data with corresponding noise files

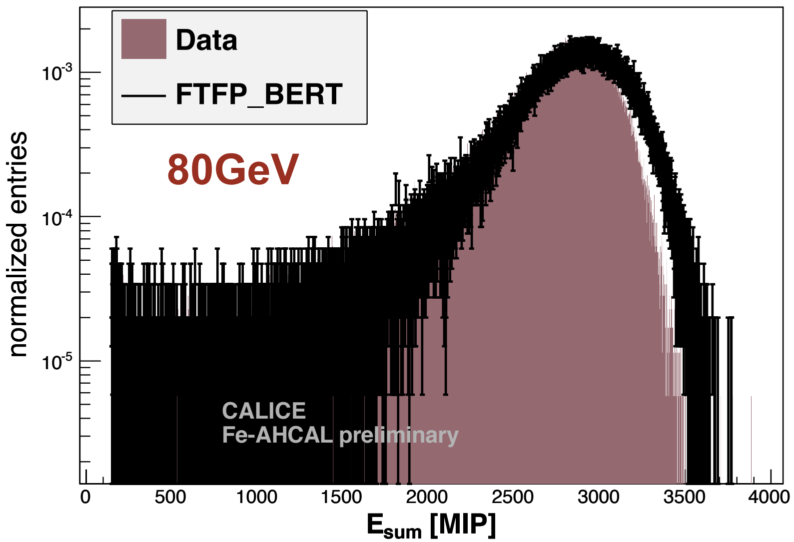
> FTFP_BERT describes HCAL response for energies below 45GeV

Pion responses in AHCAL

Analogue (12bit readout)

E_{Sum}

> Deposited Energy

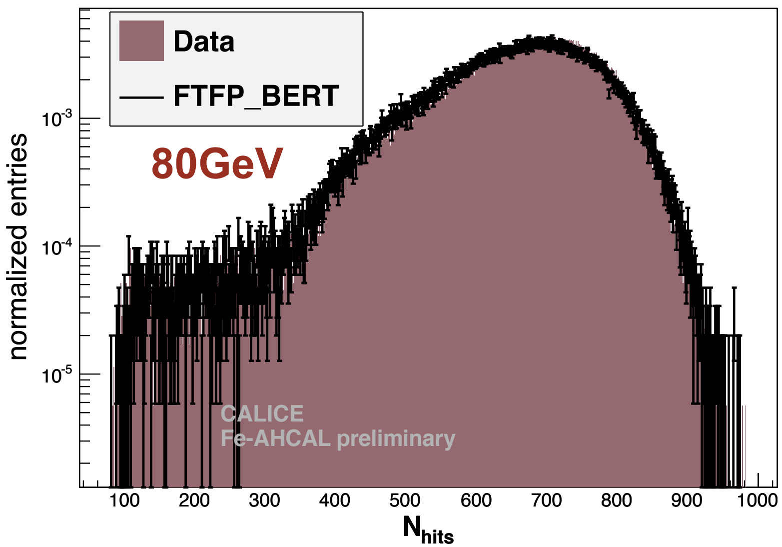


- "Standardised" mean extraction procedure
- Including impact of tails, due to leakage and saturation

Digital (1bit readout)

N_{hits}

> Number of hits

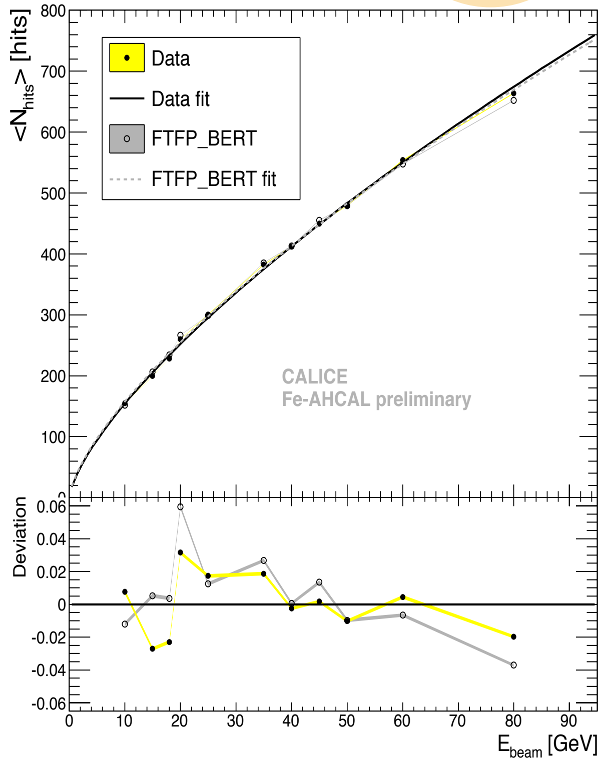


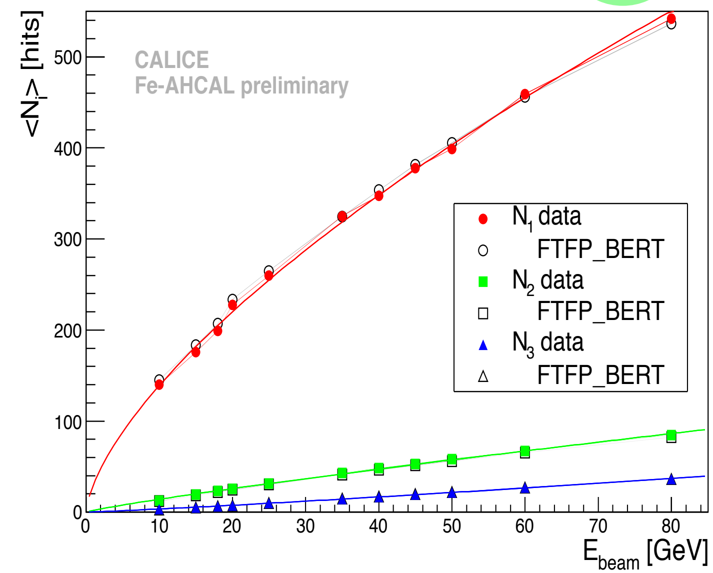
N_3 + N_2 + N_1

Semi-digital (2bit readout)

> Number of hits above 3 thresholds

Mean pion responses in AHCAL





Non-linear response

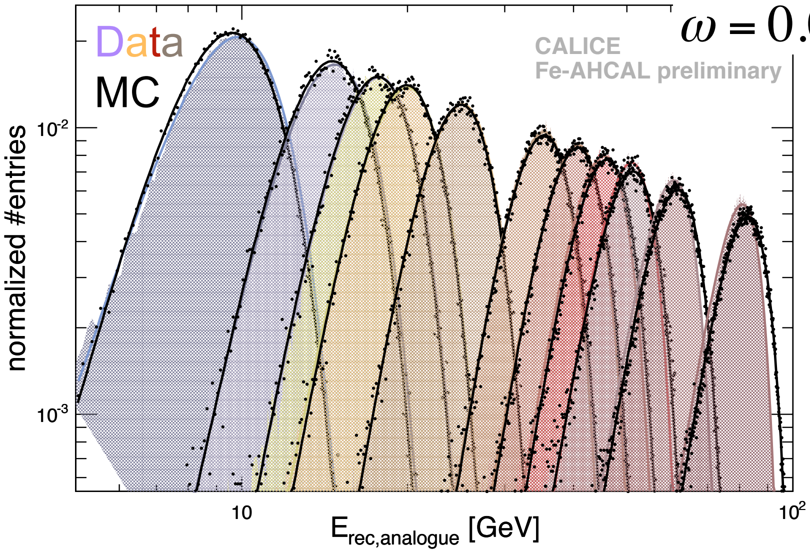
- Multi-traversing particles & pad size
- Requires more sophisticated reconstruction method to linearise

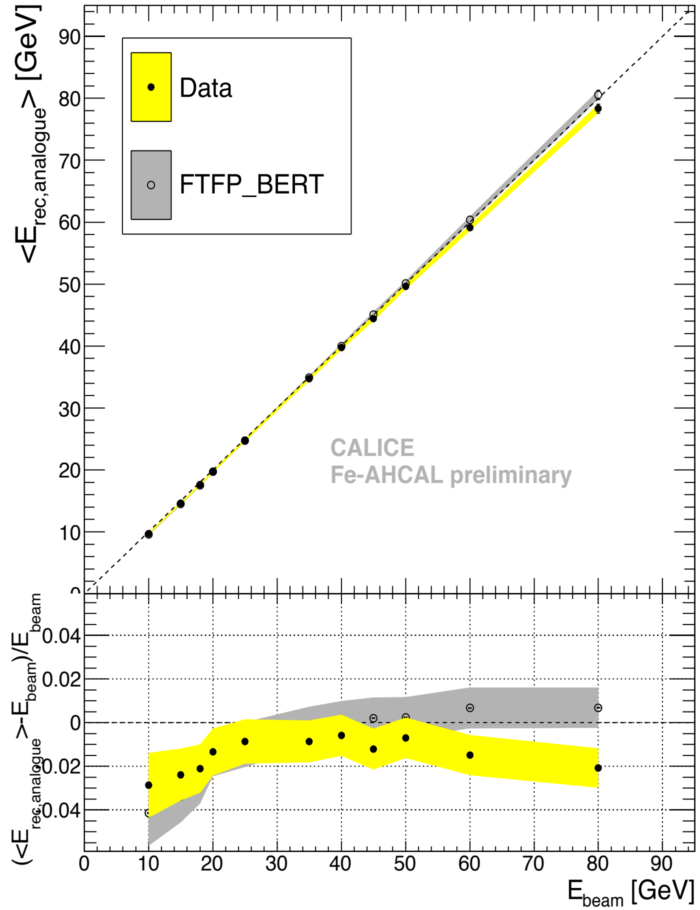
Analogue energy reconstruction

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

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

$$\omega = 0.0236GeV / MIP$$





- 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

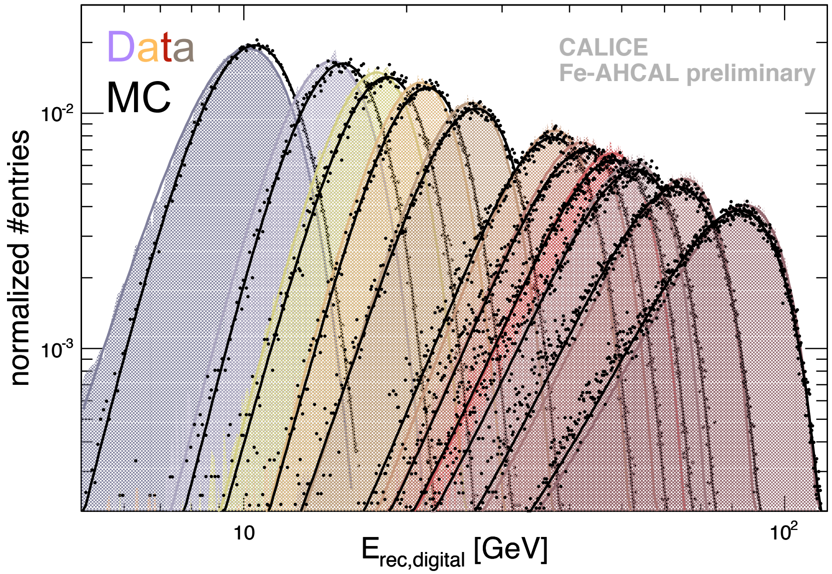
From the data fit:

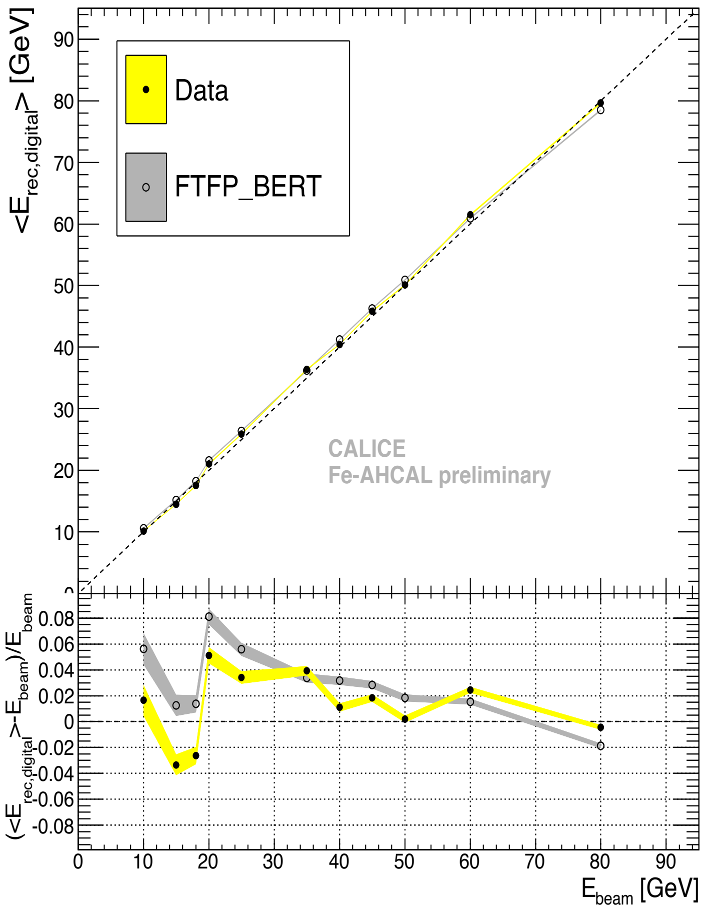
$$E_{rec,digital} = \sqrt[b]{\frac{N_{tot}}{a}}$$

$$a = 30.06 GeV^{-b}$$
$$b = 0.71$$

and assuming

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

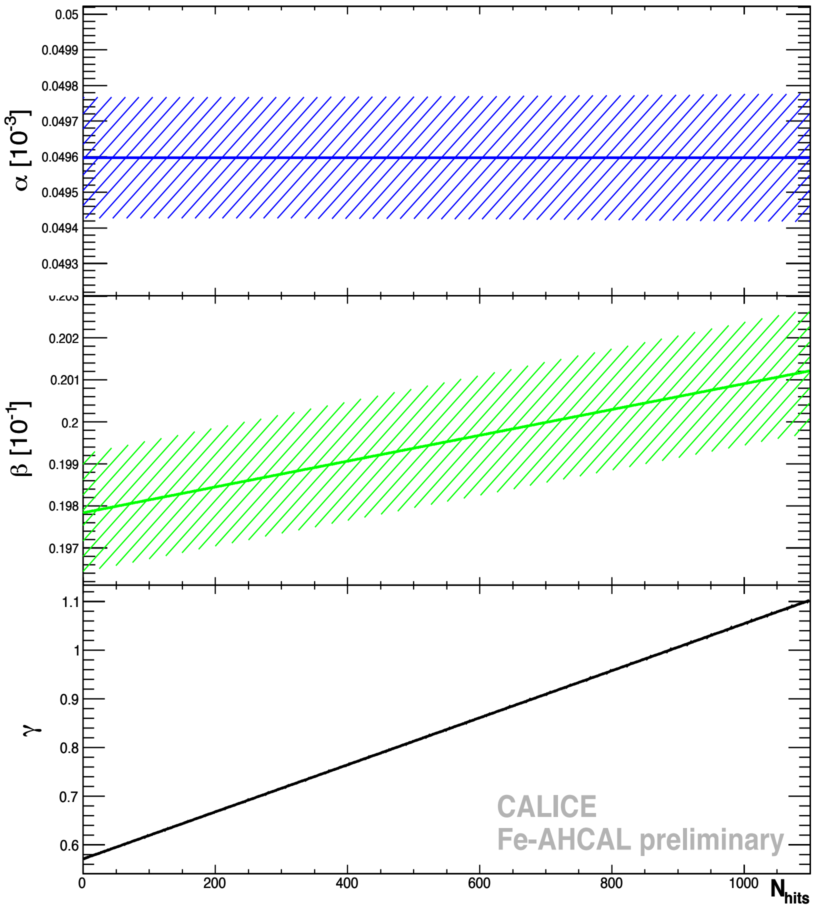




- Tail on left hand side of distributions due to multiple particles traversing same cell
- Non-linearity less than 8% after correction
- Agreement between data and MC better with increasing energies

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}

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

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

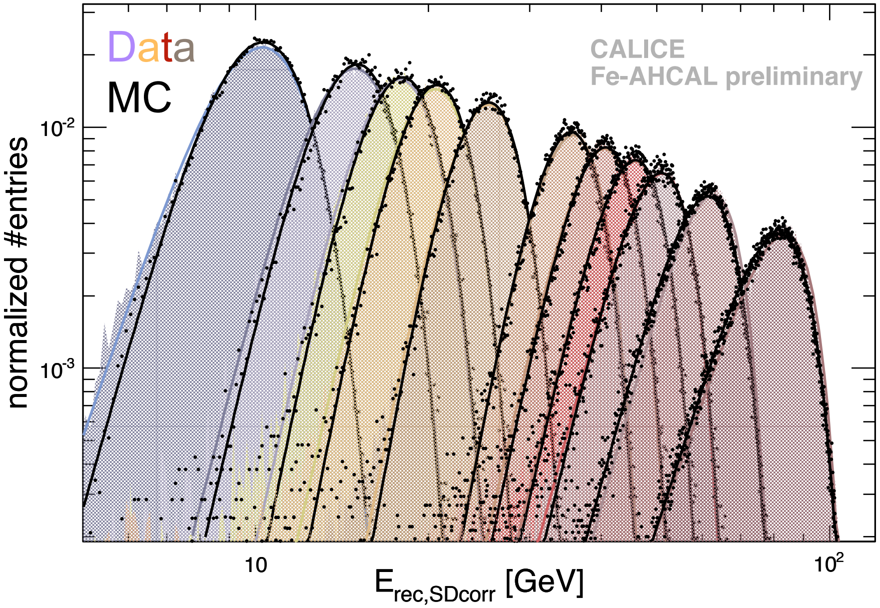
Semi-digital energy reconstruction

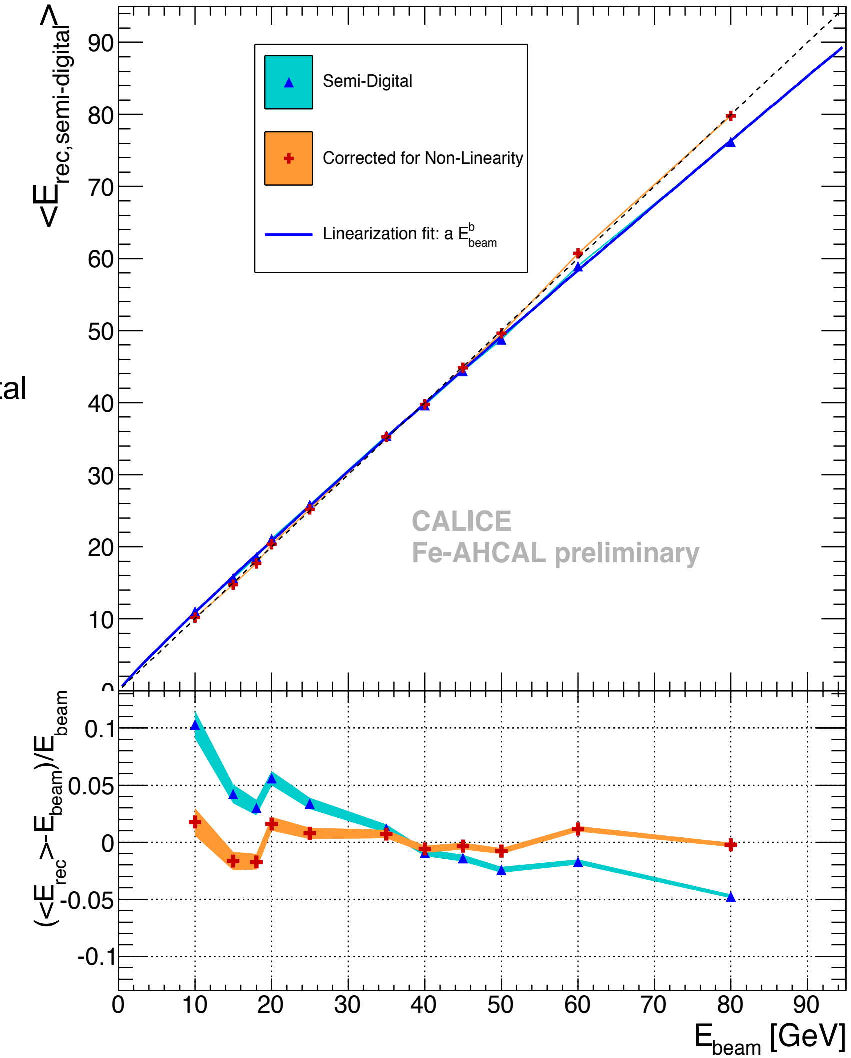
- Linearisation step similar to digital reconstruction

$$a = 1.25 GeV^{b}$$
$$b = 0.94$$

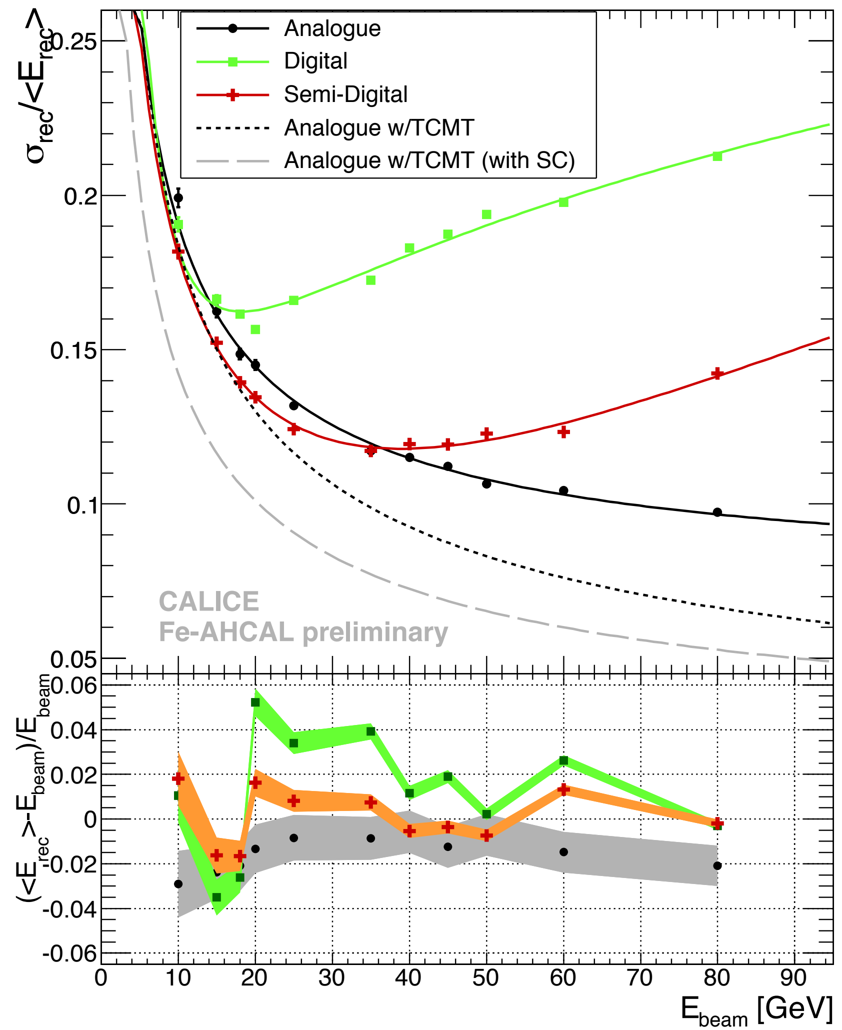
$$\boxed{E_{rec,SDcorr} = \sqrt[b]{\frac{E_{rec,semi-digital}}{a}}}$$

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





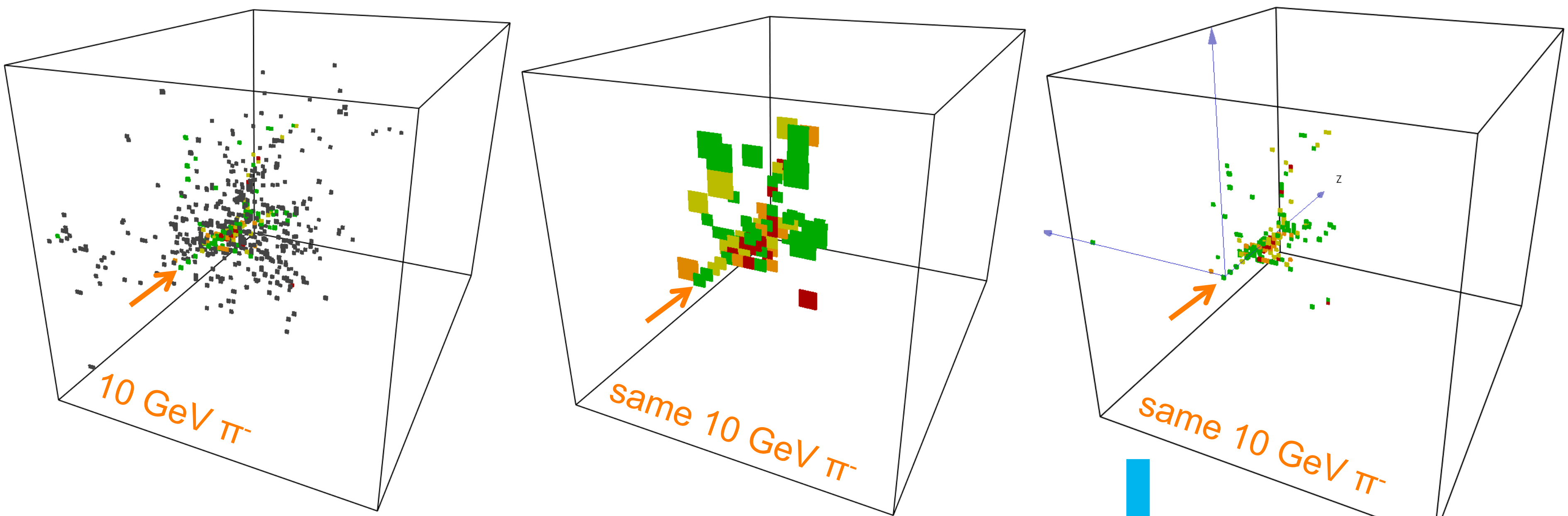
Energy Resolution



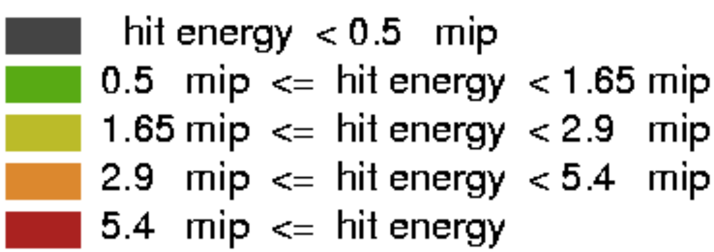
Further steps

- Study the impact on an AHCAL with 1x1cm^2 granularity, in simulation

Geant4 output | **Real AHCAL response** | **1x1cm^2 AHCAL response**

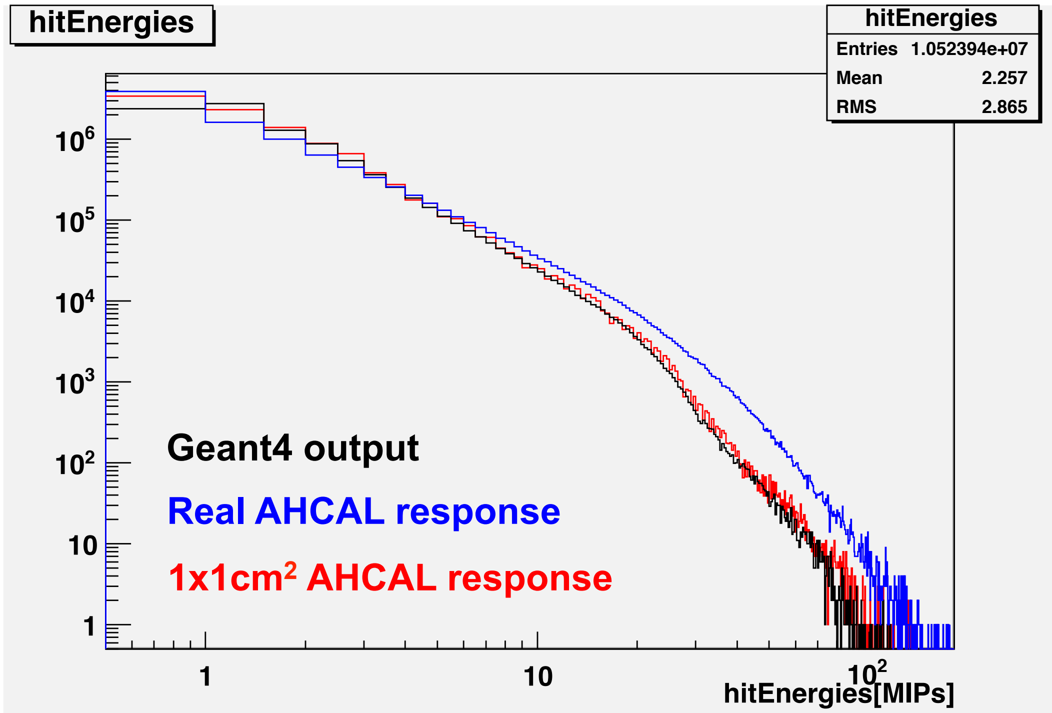


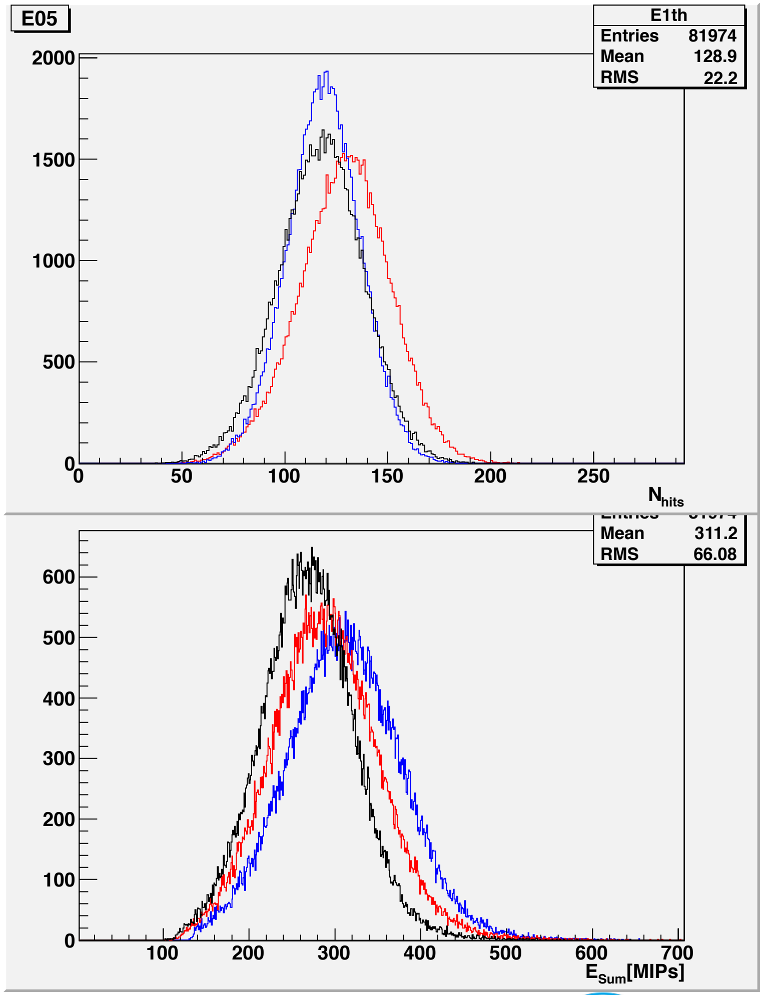
comparable with DHCAL data



Further steps

- Study the impact on an AHCAL with 1x1cm² granularity, in simulation
- 10GeV pion response

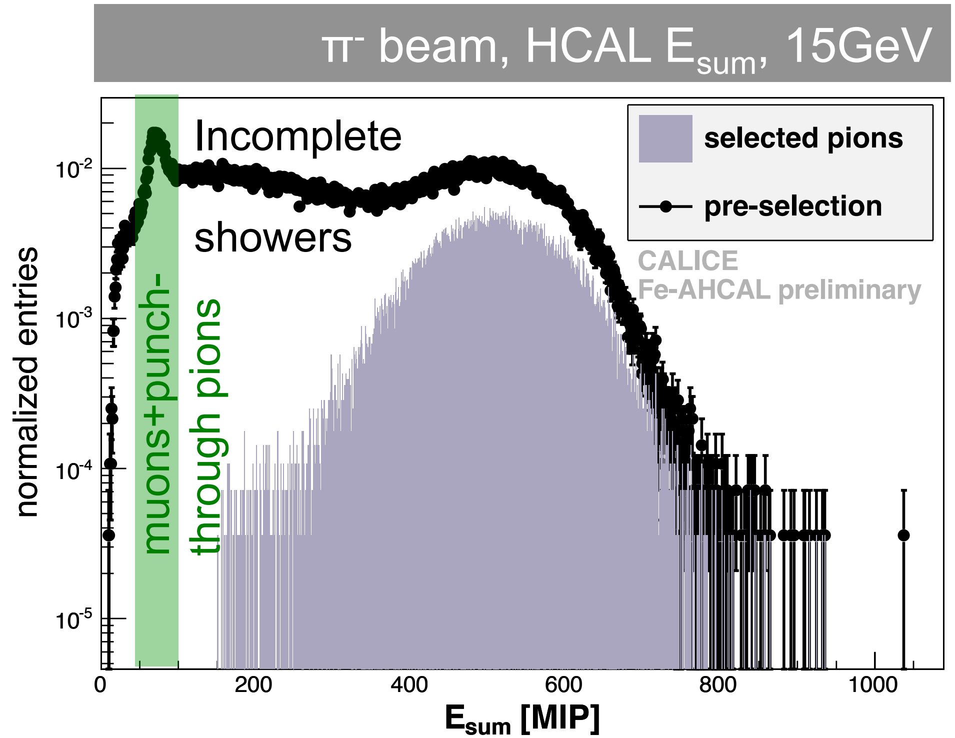




- Impact of X-talk & cell size nicely seen
- Full analysis coming soon

Backup: Event Selection

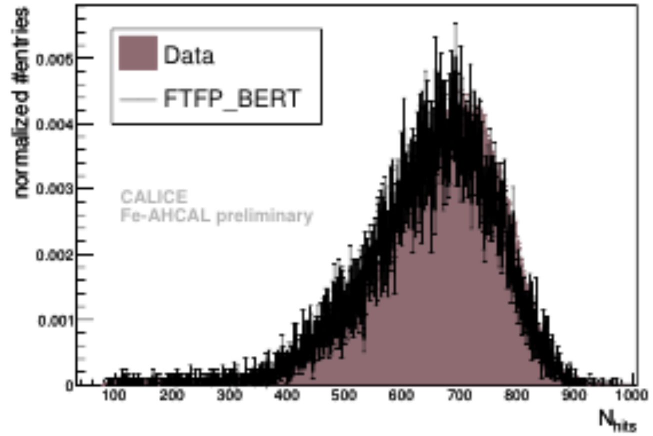
- Test beam is a composition of different particle types



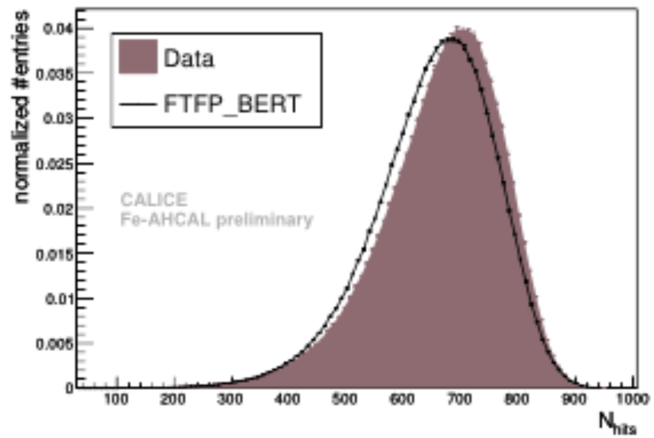
- Event selection follows „*Hadronic energy resolution of a highly granular scintillator-steel hadron calorimeter using software compensation techniques*“ 2012_JINST_7_P09017: 29 Runs, 11 Energies

Backup: Mean extraction procedure

1. Gaussian pre-fit within Mean±3RMS
2. Novosibirsk fit within μ±3σ of Gaussian (χ2<3)
3. Novosibirsk parameters for filling histogram randomly from 0 to 3σ
4. Mean & RMS of histogram



(c) Raw distributions, 80 GeV



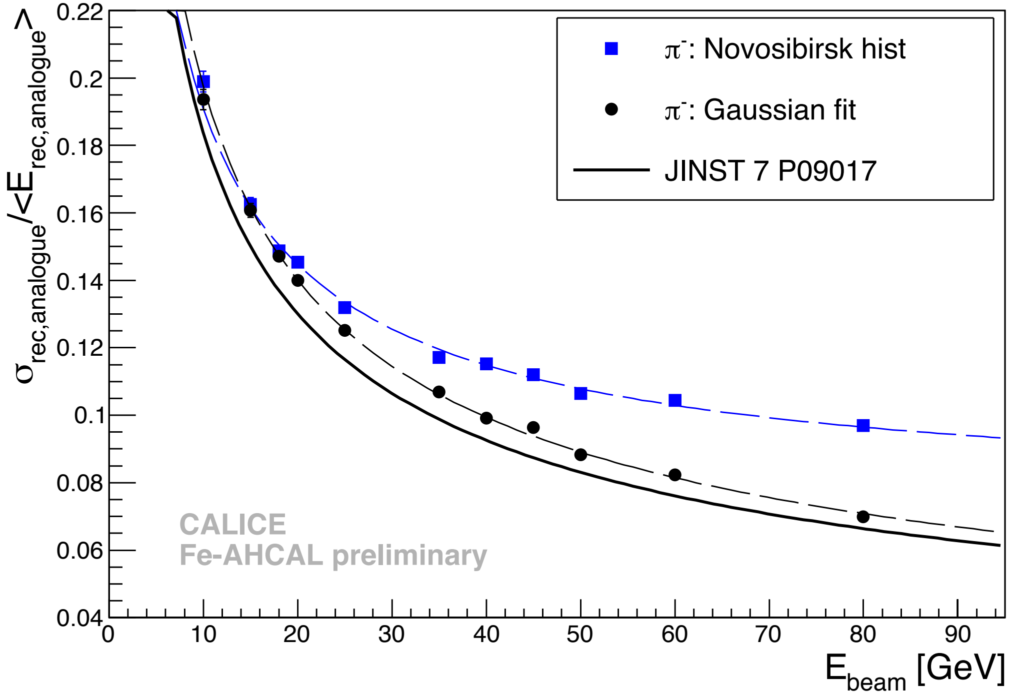
(d) Novosibirsk hist, 80 GeV

Backup

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

$$\frac{\sigma_{rec}}{\langle E_{rec} \rangle} = \frac{a}{\sqrt{E_{beam}[GeV]}} \oplus b \oplus \frac{c}{E_{beam}[GeV]}$$

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



Backup

Run list & event selection

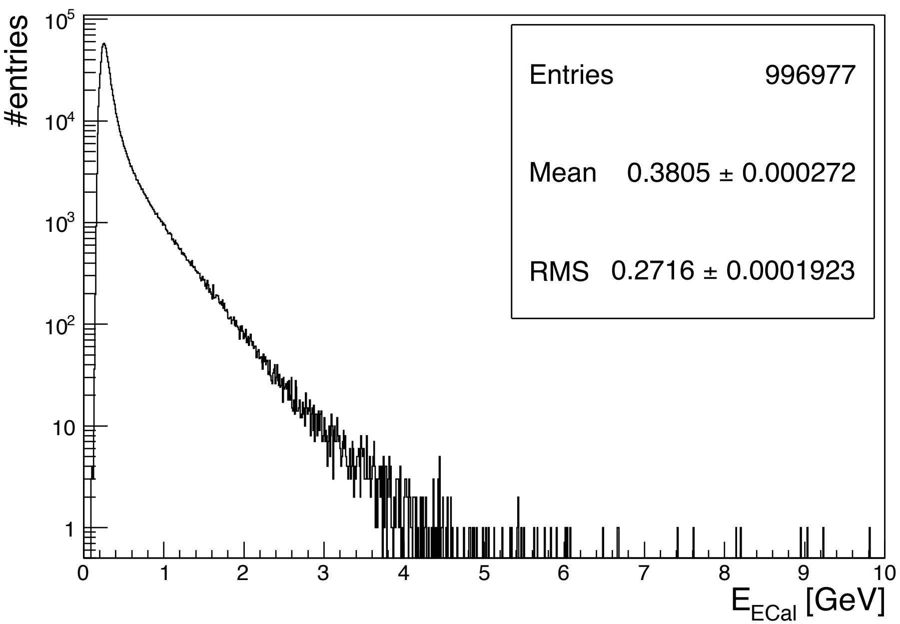
- ~20% of all event selected from data and MC

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