Energy Reconstruction in the CALICE Fe-AHCal in Analog and Digital Mode

Fe-AHCal testbeam CERN 2007

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CALICE Collaboration meeting
Argonne, 21.03.14

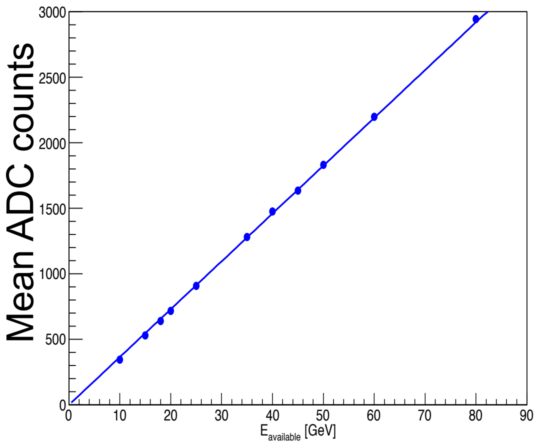
Content

- Energy Reconstruction Procedures of
  A-, SD- and D-HCal
- Data and event selection of Fe-AHCal
- Implementation of different procedures
- Impact on resolution & linearity

Measurement Observables

AHCal

E_{sum} [ADC counts]

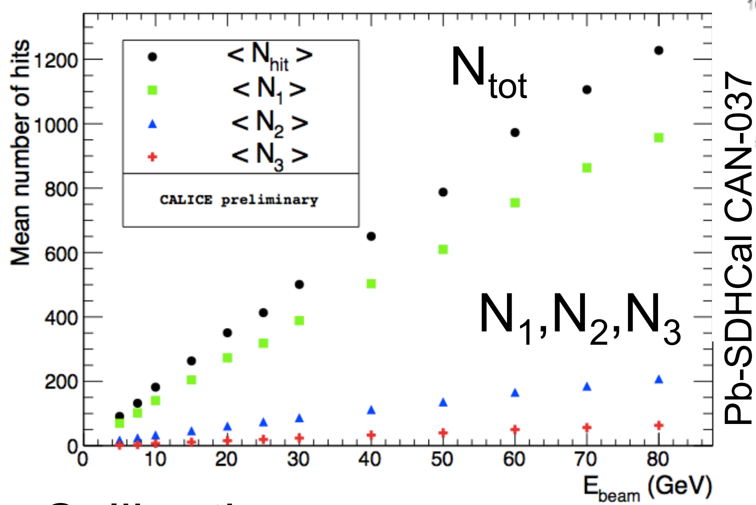


Calibration

- > Corrections for SiPMs
- > Saturation (number of pixels and dynamic range), temperature dependence

> **Differences**
> - Calibration
> - Energy Reconstruction

SDHCal

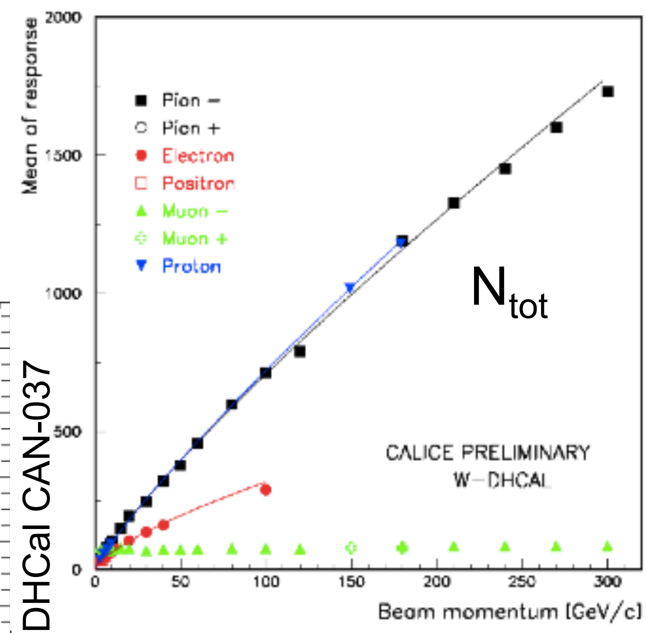


Calibration

- > Corrections for multiplicity and efficiency variations
- > Thresholds sensitive to temperature ➔pressure of RPC gas

DHCal

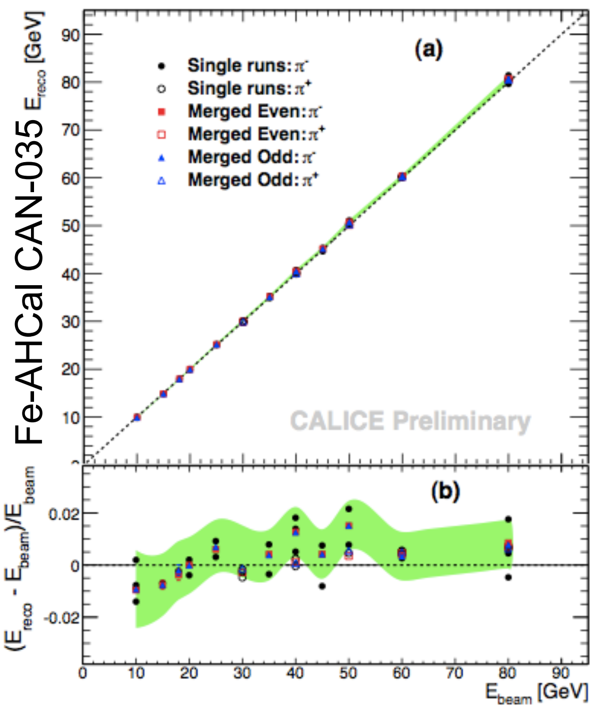
W-DHCal CAN-39



Reconstruction Procedures

AHCal

Analog mode

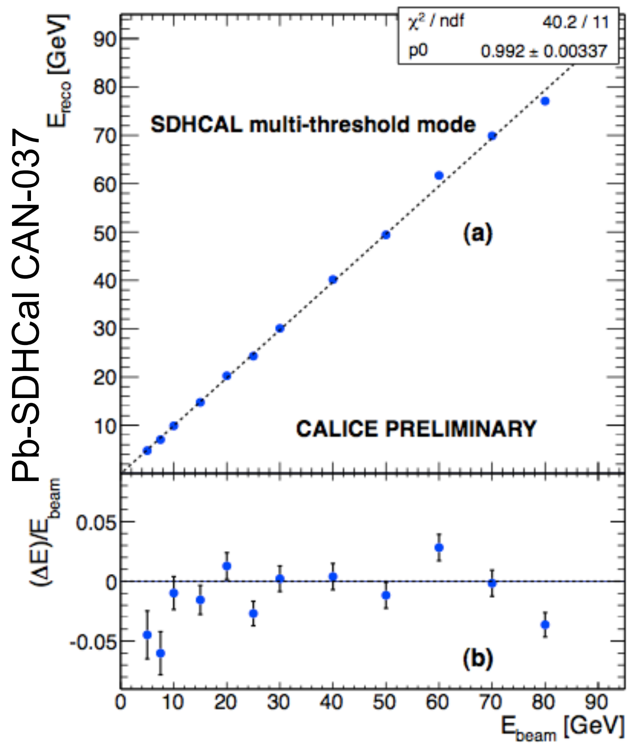


$$E_{rec,analog} = \frac{e}{\pi}\cdot\omega\cdot E_{Sum}$$

const

SDHCal

Multi-threshold mode

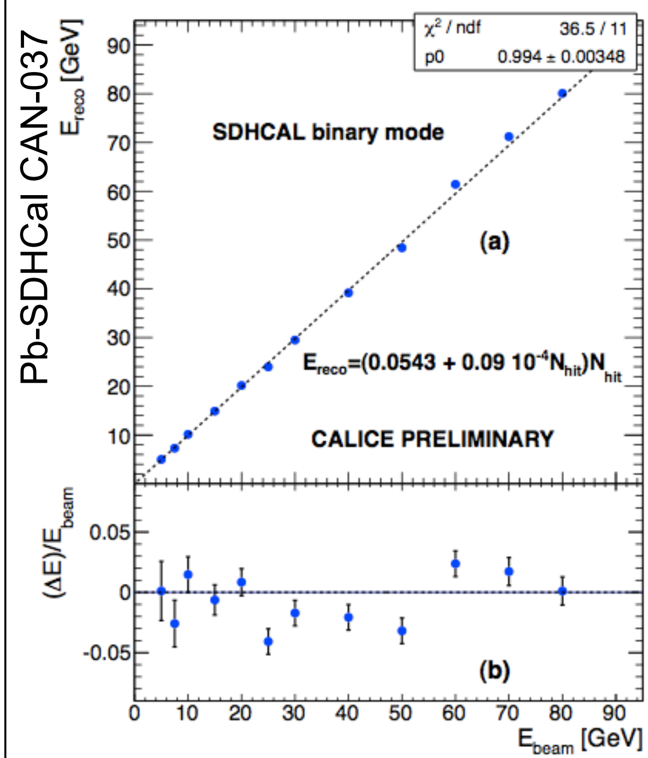


$$E_{rec,3thr} = \alpha N_1 + \beta N_2 + \gamma N_3$$

α,β and γ quadratic polynomials of N_{tot}

DHCal

Digital mode



$$E_{rec,digital} = (A + B\cdot N_{tot})N_{tot}$$

const

Idea

1. All needed parameters for procedures available in Analog HCal data, possible to study impact of reconstruction procedures
   - Implemented all 3 procedures on AHCal data

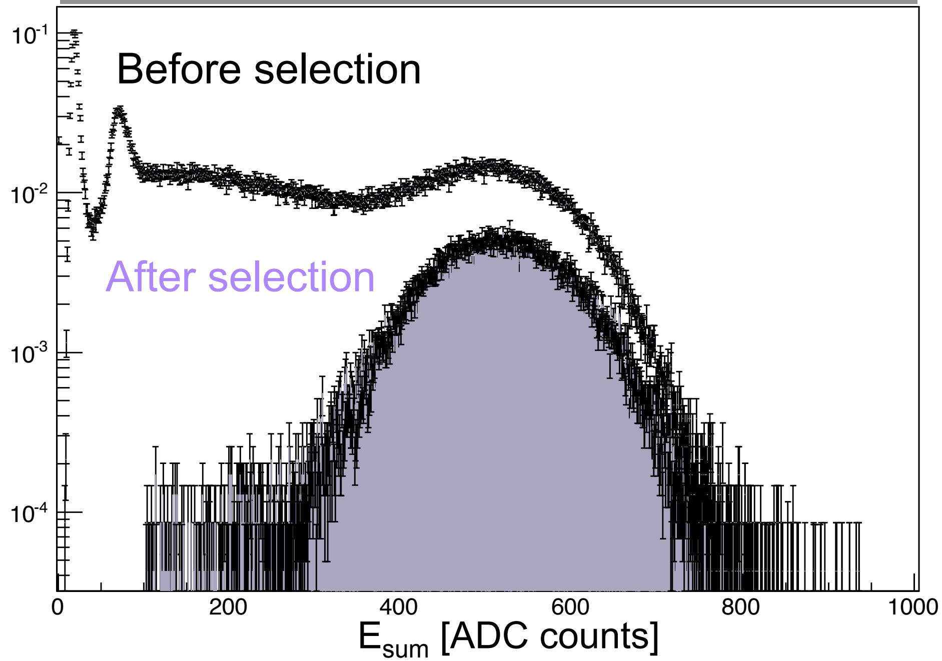
2. Generate MC sample to look into dependency on granularity
   - Possible 1x1cm^2 cell size

Fe-AHCal at CERN test beam 2007

- Reconstructed with caliceSoft v04-08, many thanks to Daniel Jeans!
- π^- event selection as well as Runs lean on CAN-035, JINST 7 P09017 (2012) respectively: 29 runs, 11 energies

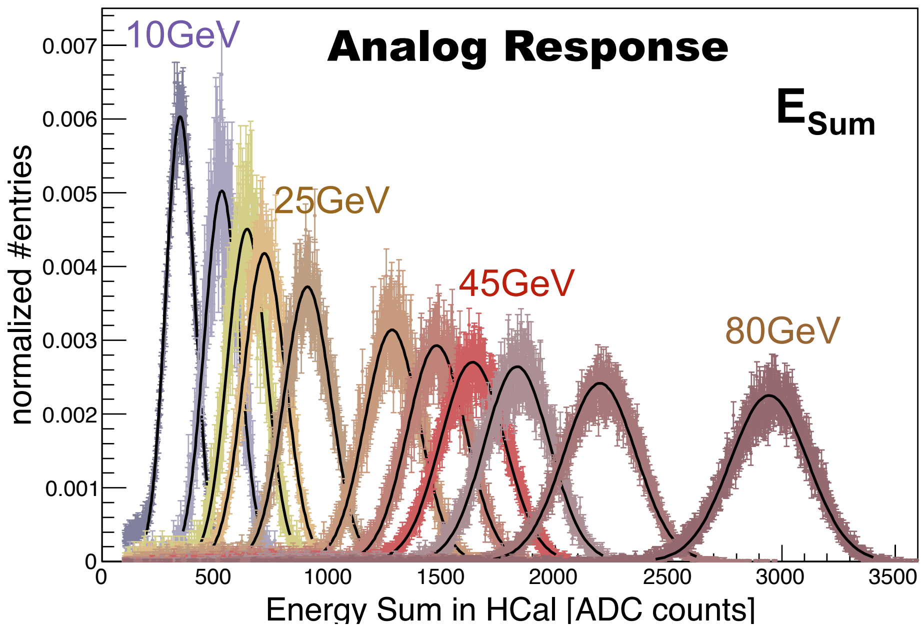
- Applied cuts for π^- selection:
  - Cherenkov counter
  - Muon Rejection: AHCal E_{Sum} > 100 MIPs
  - Shower Start in first 5 HCal layers
  - Shower rest of ECal excluded by cutting on number of hits < 50 in Ecal
  - Leakage reduced by cutting on number of hits < 10 in TCMT

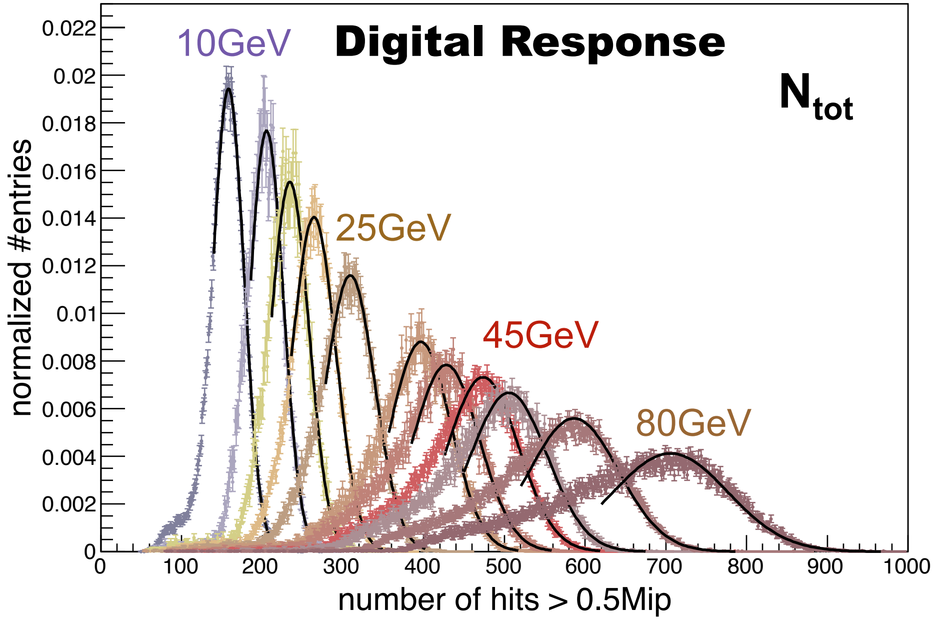
HCal energy sum, 15GeV



- Only cuts on ECal and TCMT much simpler than for paper
- MC sample not fit yet, in preparation

Analog, Digital and Semi-Digital Response





E_{beam}=10,15,18,20,25,35,40,45,50,60 and 80GeV

> Analog Response:

- Little energy leakage
- Fitted with Gaussian ± 2σ
- Most probable value for energy reconstruction

> Digital Response:

- Large left tail due to AHCal granularity
- For 10GeV cut impurities seen
- fitted with Novosibirsk, μ taken from Gauss +3 -1σ

Analog, Digital and Semi-Digital Response

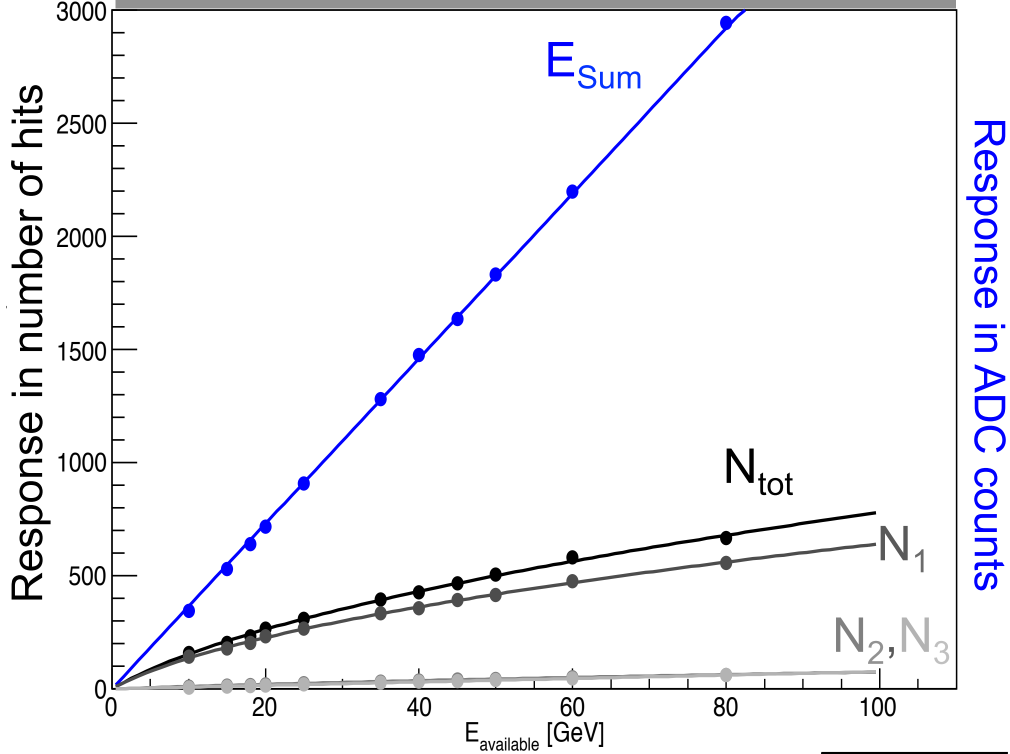
- Linear Analog response
- Non-linear Digital response
  - Due to low granularity (in comparison to DHCal prototypes)
  - Multi-traversing particles

$$N_{tot}Fit = -\frac{A}{2B} + \sqrt{\frac{E_{available}}{B} + \frac{A^2}{4B^2}}$$

  - A and B used to linearize ($E_{rec}=E_{available}$)

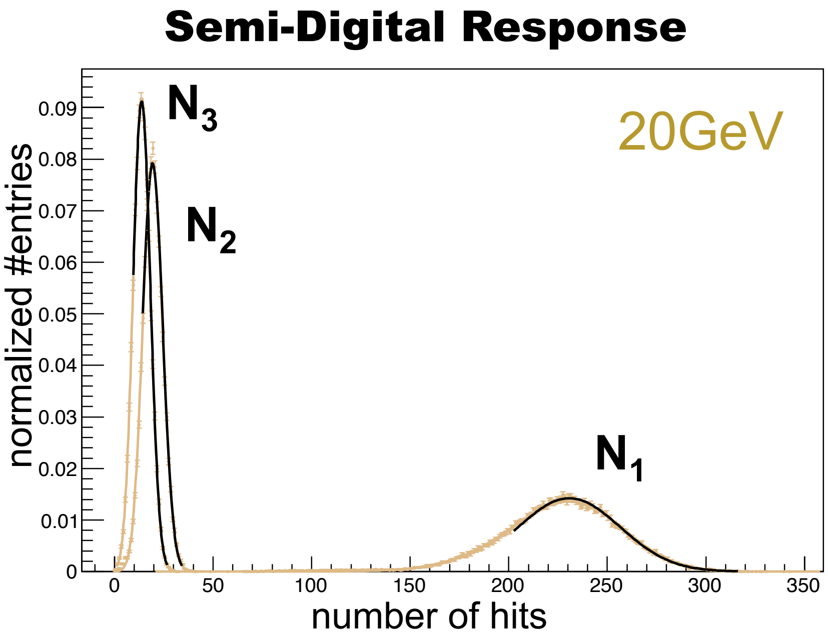
- With increasing threshold more and more linear multi-threshold response

Response in hits and ADC counts



$$E_{available} = \sqrt{p_{beam}^2 + m_{pi}^2}$$

Analog, Digital and Semi-Digital Response



> Semi-digital Response

- **N_1** = 0.5MIPs < hits < 5MIPs
- **N_2** = 5MIPs < hits < 10MIPs
- **N_3** = hits > 10MIPs
- **N_{tot}** = $N_1+N_2+N_3$= hits > 0.5MIPs

(Values for threshold taken from CAN-037)

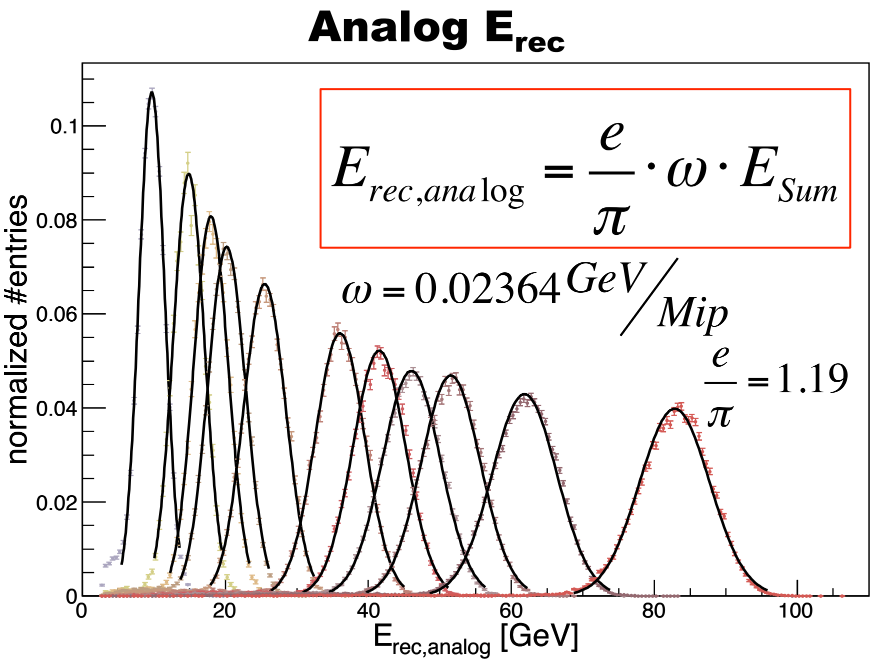
- 4 times digital response for each energy
- Decreasing tails with increasing threshold

> Semi-digital energy reconstruction requires

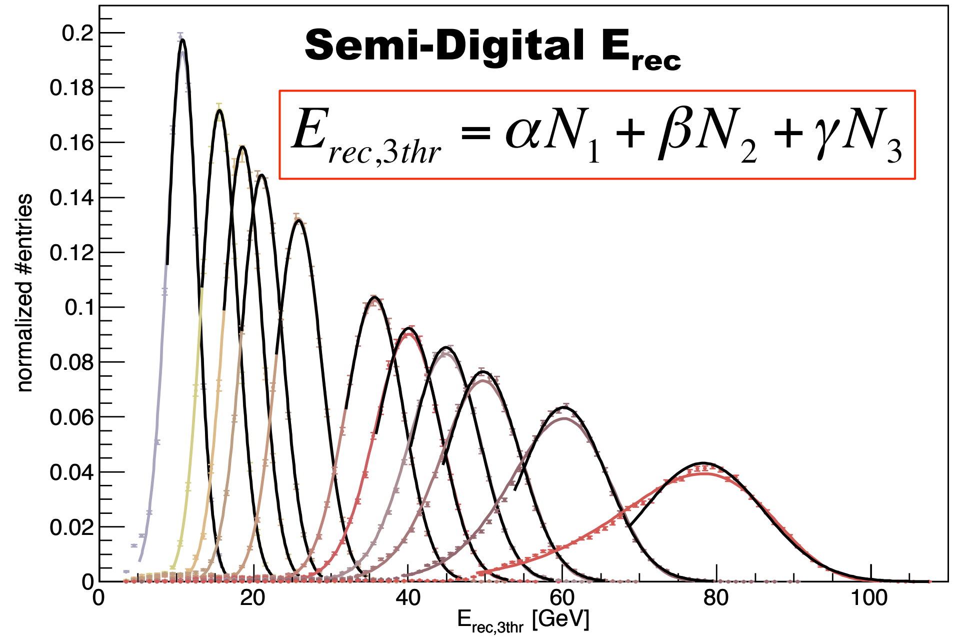
- minimization of X^2
- 15.000 events of each energy
- Extract α,β and γ for multi-threshold energy reconstruction

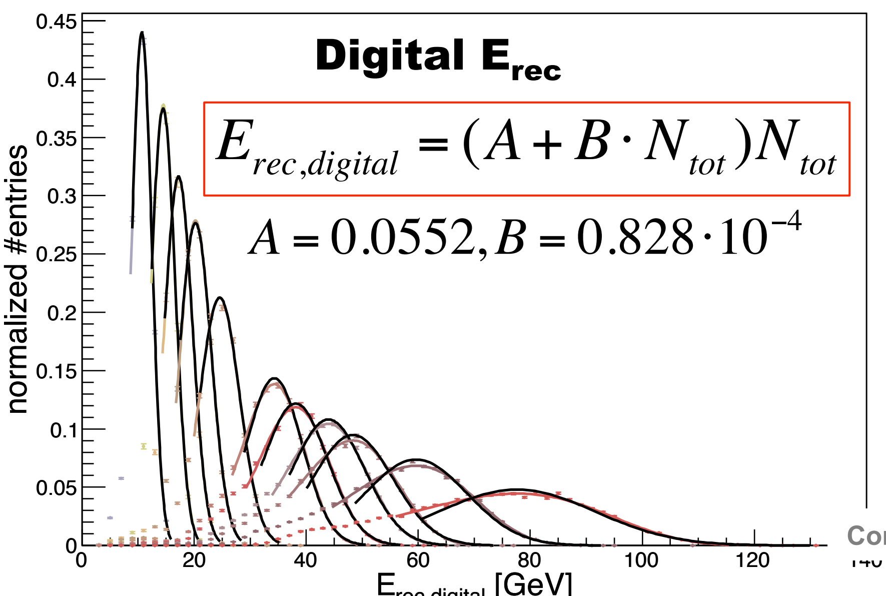
$$\chi^2 = \sum_i^{events} \frac{\left((\alpha N_1 + \beta N_2 + \gamma N_3) - E_{true}\right)^2}{E_{true}}$$

Reconstructed Energy



Values: CAN-035, respective paper





- For $E_{rec,3thr}$ α,β & γ calculated by χ^2 minimization
- E_{rec} distributions fitted in the same way as the response (σ,μ taken from Gauss)

Resolution & Linearity

WORK IN PROGRESS

$$ResolutionFit = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

Digital mode

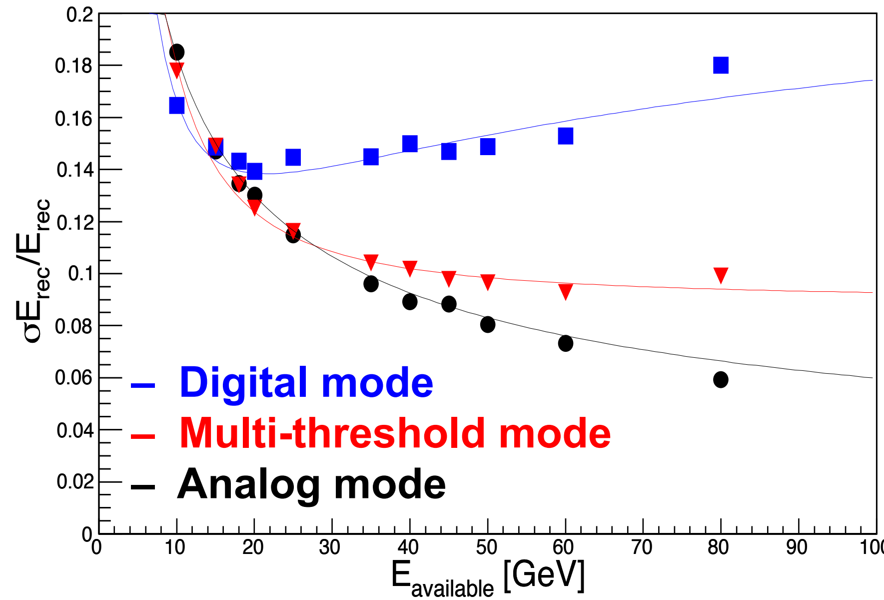
- Data points jumpy, improvement in cuts
- Best resolution for 10GeV
- Linearity < 7%

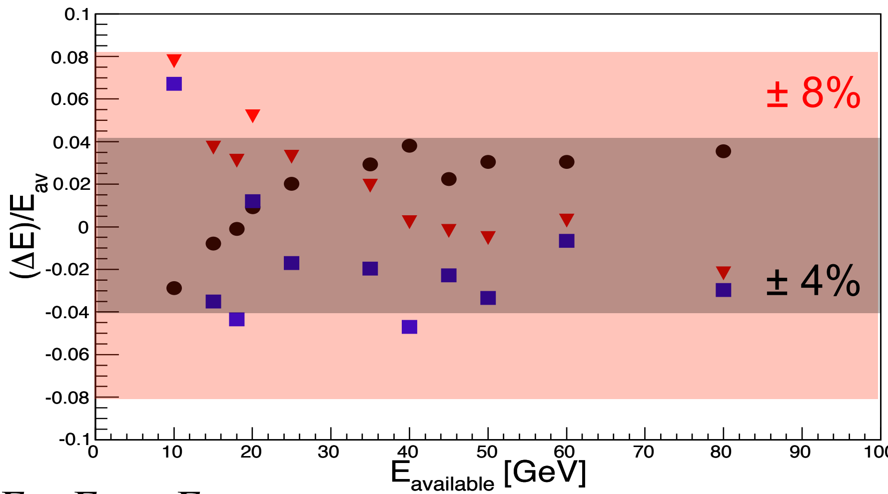
Multi-threshold mode

- Achieves analog resolution < 30GeV
- Linearity < 8%

Analog mode

- Data points agree nicely with fit (values taken from Software Compensation paper)
- Best resolution > 30GeV
- Linearity < 4%





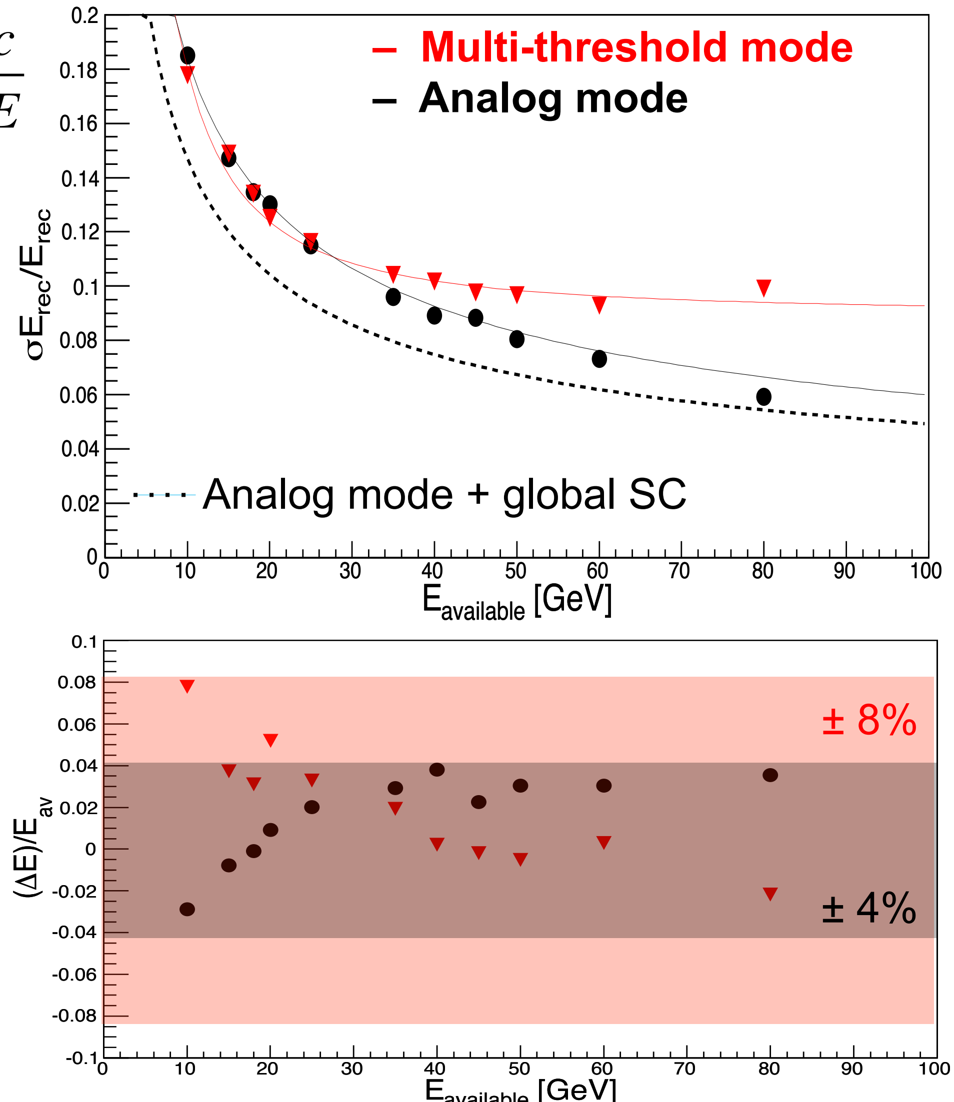
$$\Delta E = E_{rec} - E_{available}$$

Resolution & Linearity

WORK IN PROGRESS

$$ResolutionFit = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

- AHCal + software compensation
  - Global software compensation (C. Adloff *et al.*, "**Hadronic energy resolution of a highly granular scintillator-steel hadron calorimeter using software compensation techniques**", *arXiv:1207.4210*)
  - Best resolution
- How far can we improve the Multi-threshold mode?
  - Implement global software compensation technique



$$\Delta E = E_{rec} - E_{available}$$

Global Software Compensation

WORK IN PROGRESS

- Weighting of shower energy with single weight depending on fraction of EM sub-shower
  - Weight c_{global} derived by hit energies (higher energy density for em hits)

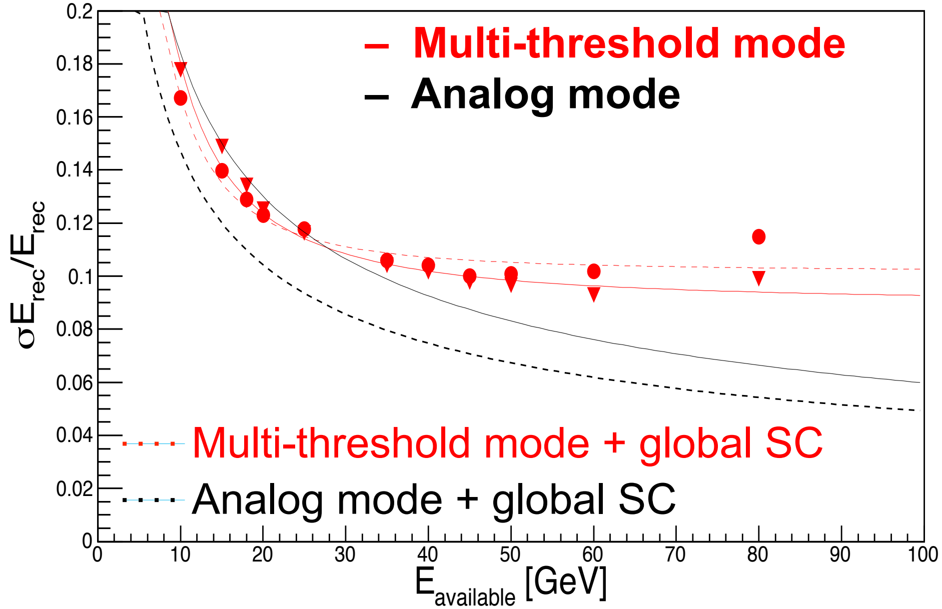
$$c_{global} = \frac{hits > 5Mip}{hits > MeanEnergySpectrum}$$

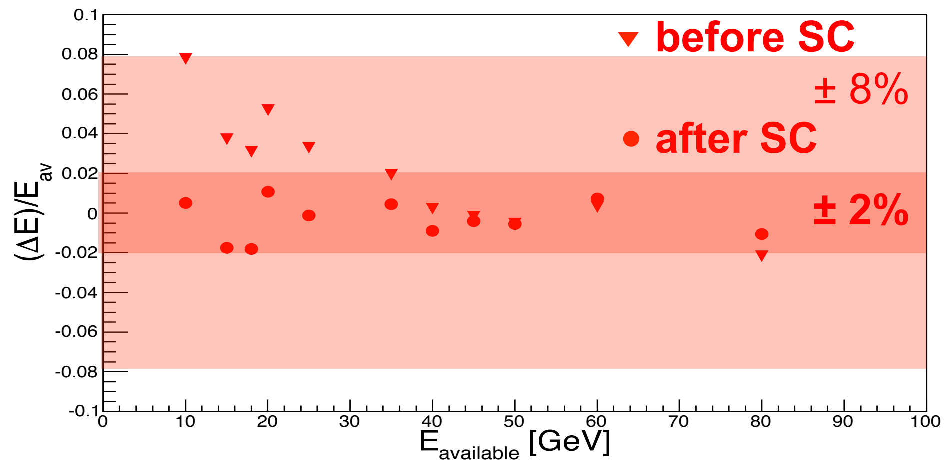
$$E_{shower} = c_{global} \cdot E_{rec,3thr}$$

  - Linearization of E_{shower}

$$E_{GC} = a_0 + a_1 E_{shower} + a_2 E_{shower}^2$$

- Little improvement for lower energies, for 60 and 80GeV worsening of resolution by improvement of linearity





$$\Delta E = E_{rec} - E_{available}$$

Conclusions & Outlook

- **Digital** read out of AHCal prototype may improve resolution for energies < 15GeV
- **Semi-digital** mode achieves similar resolution as Analog mode for energies < 30GeV
- **Analog** energy reconstruction shows the best resolution for higher energies
- **GSC** improves Analog, but only partially Semi-digital resolution

THINGS NEED TO BE DONE…

- Data-MC comparison for TB Cern 2007
- Improvement of Cuts: especially seen for 10GeV

WHEN THINGS ARE DONE…

- Writing of CALICE note together with M. Gabriel, who will complement the Analysis by a SC study of full System (ECal+HCal+TCMT)
- Presenting of the Analysis at the TIPP conference in June

> Thank You for Your Attention!

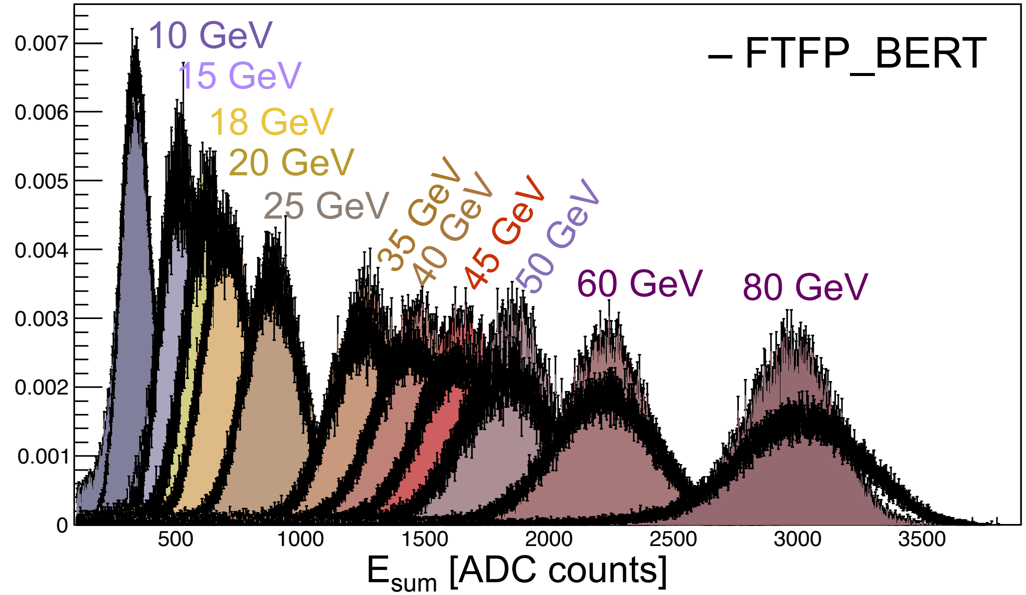
Fe-AHCal at CERN test beam 2007

- Reconstructed with caliceSoft v04-08, many thanks to Daniel Jeans!
- π^- event selection as well as Runs lean on CAN-035, JINST 7 P09017 (2012) respectively
- π^- MC samples generated (100.000 events per Run, FTFP_BERT physics list), only for HCal (particle gun position in front of HCal), digitized with caliceMarlin v04-07 (Mip2GeV=0.000846 , x-talk=15%)

WORK IN PROGRESS

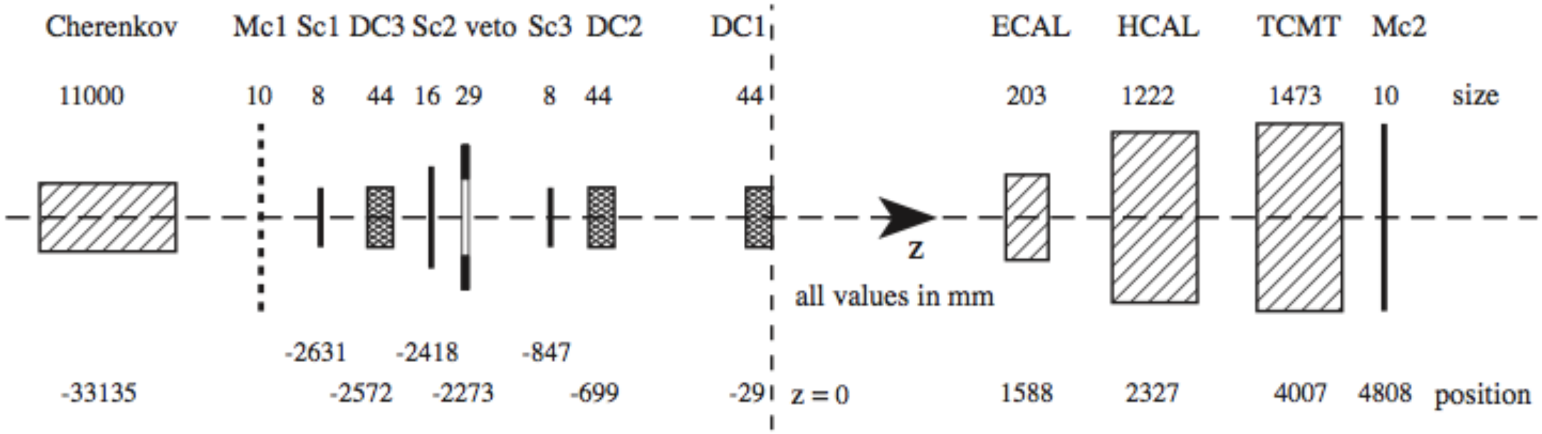
- Applied cuts :
  - Muon Rejection: AHCal E_{Sum} > 100 MIPs
  - Shower rest of ECal excluded: Shower Start in second 5 HCal layers
  - Leakage reduced by cutting on number of hits in last 3 HCal layers < 3

HCal energy sum for data+MC



TB Setup

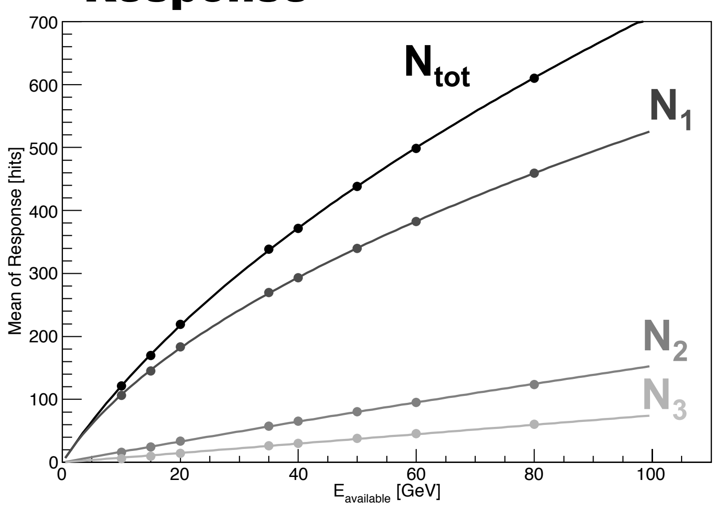
- 30 layer Silicon Ecal in 3 section with different absorber thicknesses
- 38 AHCal layers, 5mm thick plastic scintillator tiles 3x3, 6x6 and 12x12cm^2
  - 7608 scintillator cells
  - 1.04 cm thick absorber
- 16 TCMT layers 320 1m long scintillator strips
- In total 12 nuclear interactions lengths, 17648 read out channels



Multi threshold combination method

- Idea: distinguish between em and hadronic components of showers due to energy deposit
- Hits above thresholds:
  - $\mathbf{N_1}$ = 0.5 MIPs < hits < 5 MIPs
  - $\mathbf{N_2}$ = 5 MIPs < hits < 10 MIPs
  - $\mathbf{N_3}$ = hits > 10 MIPs
  - $\mathbf{N_{tot}} = N_1+N_2+N_3$
    = hits > 0.5 MIPs

Response



RPC-SDHCal method (CAN-037)
multi threshold mode (3 thresholds)

1. Hit Combination:

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

$$\alpha = a_1 + a_2 N_{tot} + a_3 N_{tot}^2,$$
$$\beta = b_1 + b_2 N_{tot} + b_3 N_{tot}^2,$$
$$\gamma = c_1 + c_2 N_{tot} + c_3 N_{tot}^2$$

2. Parameter characterisation by minimization of:

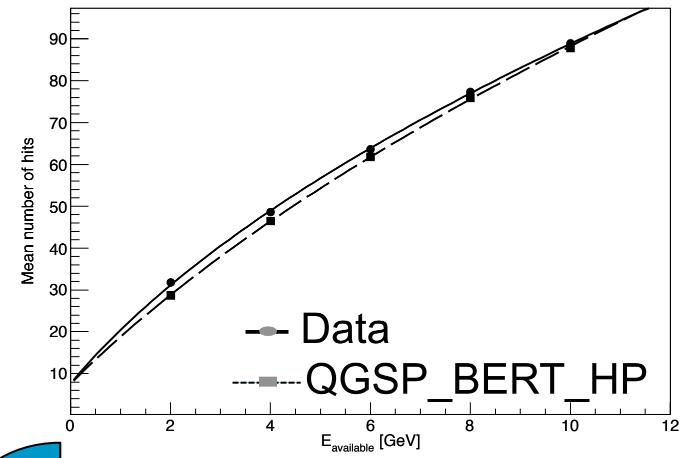
$$\chi^2 = \sum_i^{events} \frac{\left(E_{rec,3thr} - E_{true}\right)^2}{E_{true}}$$

- α,β and γ are polynomial of N_{tot} thus give energy dependent weight to hits above different threshold

DESY

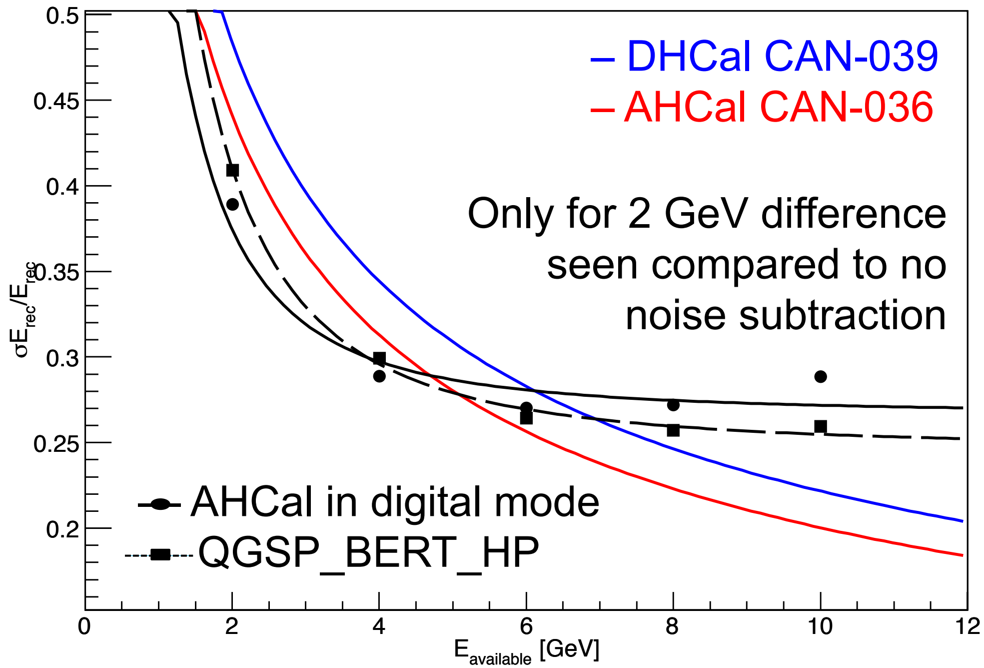
Low energy W-AHCal TB Cern noise included

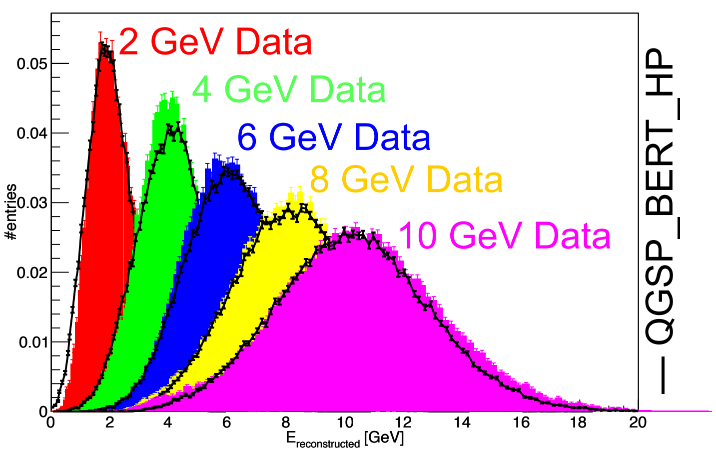
Noise of 7.6 hits

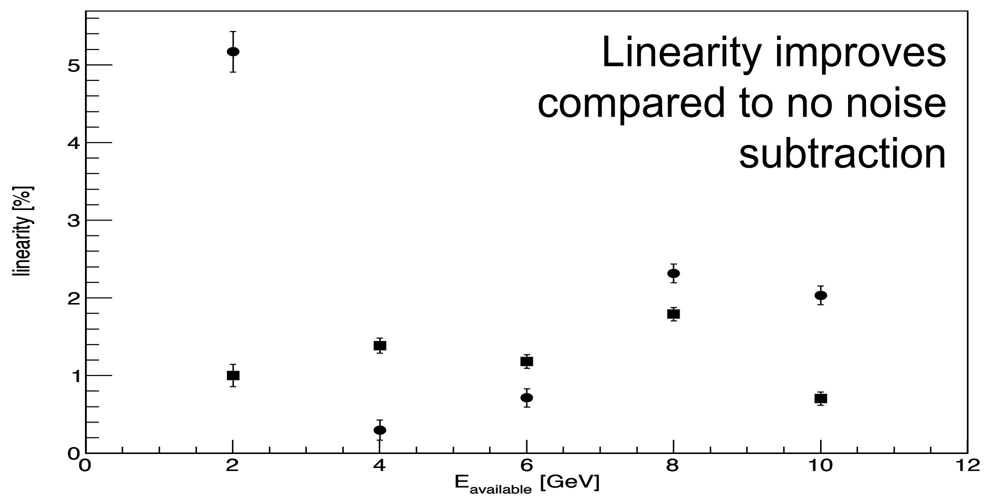


New parameters for linearization

➔ Reconstructed energy



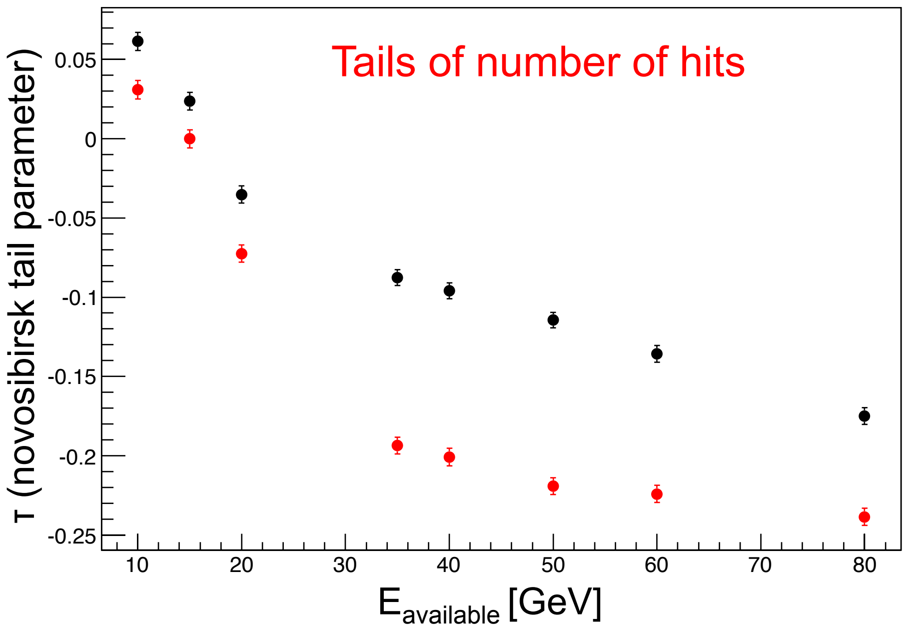




Reconstructed energy with&without leakage

Normal pion selection

Tails of energy sum



selection with hard leakage cut

Tails of energy sum