Digital analysis of AHCal testbeam data

W-AHCal testbeam CERN 2010

Fe-AHCal testbeam CERN 2007

Coralie Neubüser
AHCal main meeting
Hamburg, 09.12.13

Content

- Digital analysis of low energy CERN TB (10 GeV) W-AHCal data
- (Semi-) digital analysis of high energy CERN TB Fe-AHCal simulated MC data

W-AHCal PS CERN TB 2010

1-10 GeV beam momenta, tungsten absorber

AHCal and DHCal prototype tested with same absorber stack

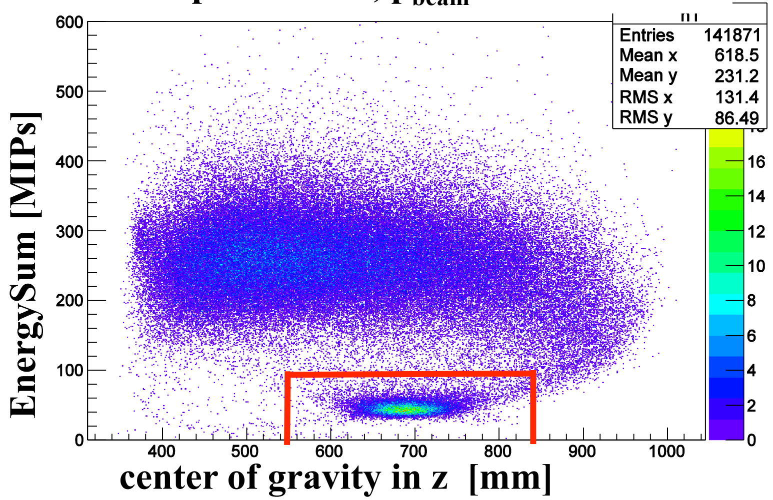
- 30 scintillator layers
- 3x3,6x6 & 12x12 cm^2
- ~ 6 500 channels
- Monte Carlo detector model completed and nicely working ("TBCern2010", see CAN-036)

- 39 RPC layers
- 1x1 cm^2
- ~ 50 000 channels
- Simulations not ready

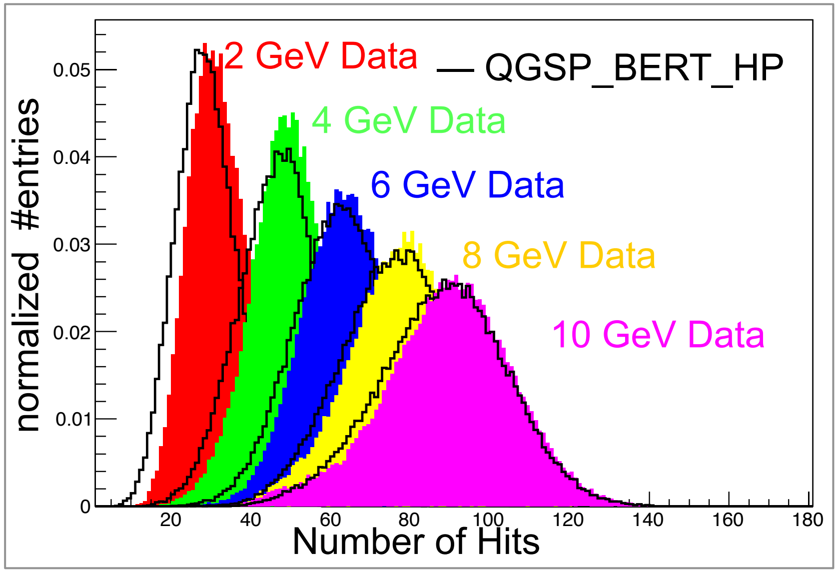
- Monte Carlo Sample for AHCal was generated:
  - Geant4 version 4.9.6 patch1, physics list: QGSP_BERT_HP
  - Particle gun position directly (3mm) in front of the HCAL (punch through pions/muons seen)

Pion event selection & response in hits

- BeamBit, BadLedCut, VetoRegion Cut, List of noisyCells, Cherenkov Counter
- Muon rejection:
  - Cuts on energy sum and number of hits for different energies



Number of hits above 0.5 MIPs

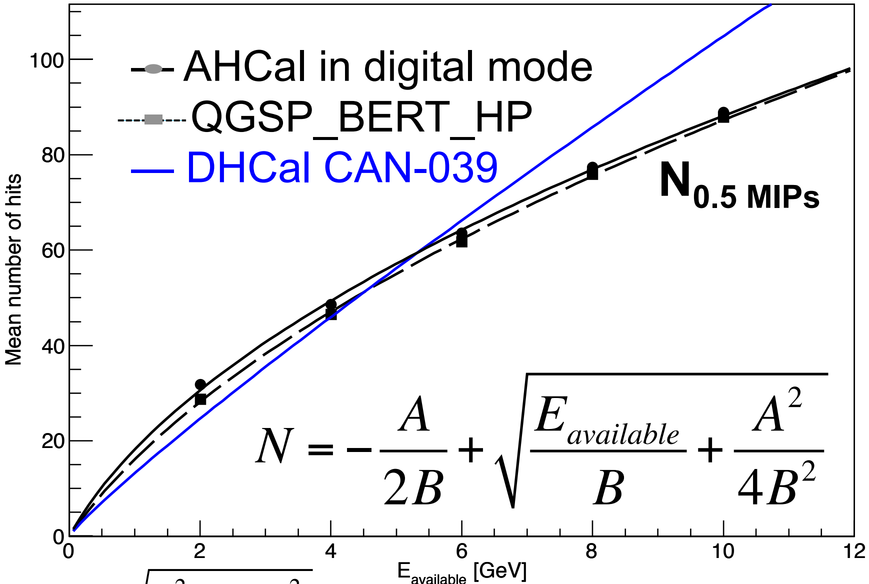


Run numbers: 360463, 360774, 360771, 360767, 360737

- Monte Carlo sample shifted to smaller number of hits

Response & energy reconstruction

- Response taken from mean number of hits and fitted with root function
- AHCal response clearly not linear, mean number of noise hits ~ 7 (upcoming PhD thesis C.Günther)



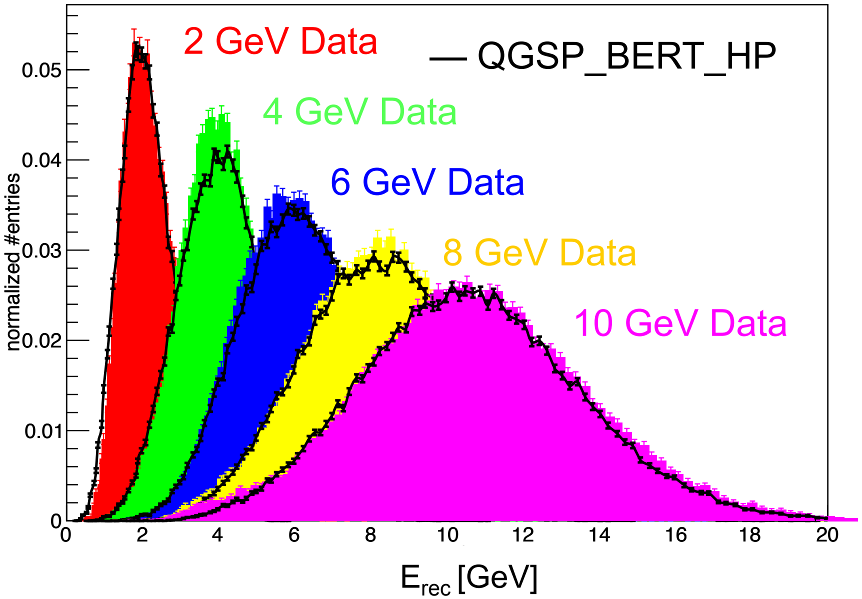
$$E_{available} = \sqrt{p_{beam}^2 + m_{pi}^2}$$

- DHCal very linear (higher granularity & layer number), no noise (see CAN-031)

- Linearization of the response ($E_{available} = E_{rec}$)

$$E_{rec} = (A + B \cdot N)N$$

$$A = 0.0398 GeV / hit, B = 0.0008 GeV / hit$$



- Mean reconstructed energy tending to higher values
  - MC and Data in agreement

Resolution & Linearity

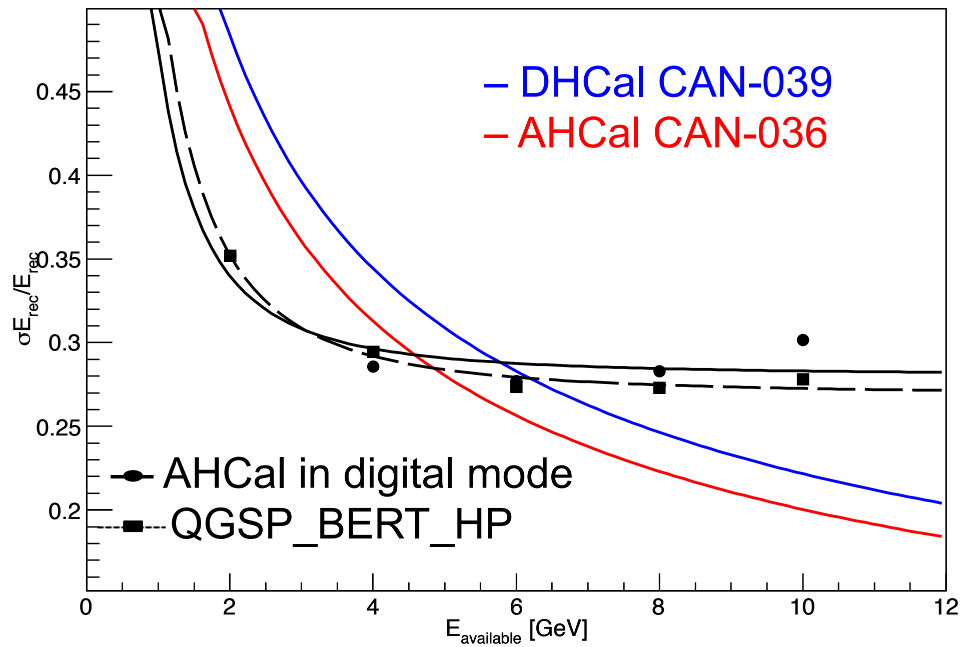
- Resolution best for AHCal in digital mode E < 6 GeV (counting hits above 0.5 MIPs)
  - Reason: AHCal in low energy prone to Landau fluctuations

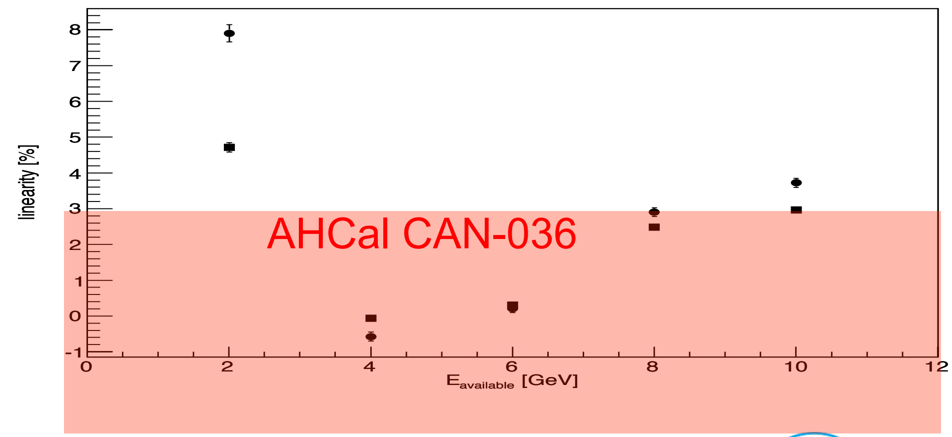
$$resolution = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

- E > 6 GeV: DHCal better than AHCal in digital mode
  - Reason: higher granularity
- But AHCal best
- Linearity looks resonable for all methods < 8%

$$linearity = \left(\langle E_{rec} \rangle - E_{available}\right) \Big/ E_{available}$$

WORK IN PROGRESS





First conclusions

- Counting hits can improve the resolution of analog HCal for low energies
- Higher energies very interesting, BUT calibration on W-AHCal side not ready yet

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ADDITIONAL INTERESTING STUDY

- Semi-digital readout of AHCal data (further improvement with additional thresholds possible?)
- Therefore MC sample of TB 2007 Cern AHCal generated (38 layers)
  - Fe absorber → less dense showers, less saturation effects

TB CERN 2007 – MC pion sample

- Monte Carlo Sample was generated:
  - Particle gun position directly in front of the HCal (punch through pions/muons seen)
  - Cuts: ShowerStart in first 5 layers, preShowerCut, VetoRegionCut, BadLED and MuonRejectionCut

Mip2GeV: 0.000846
xTalk: 0.15

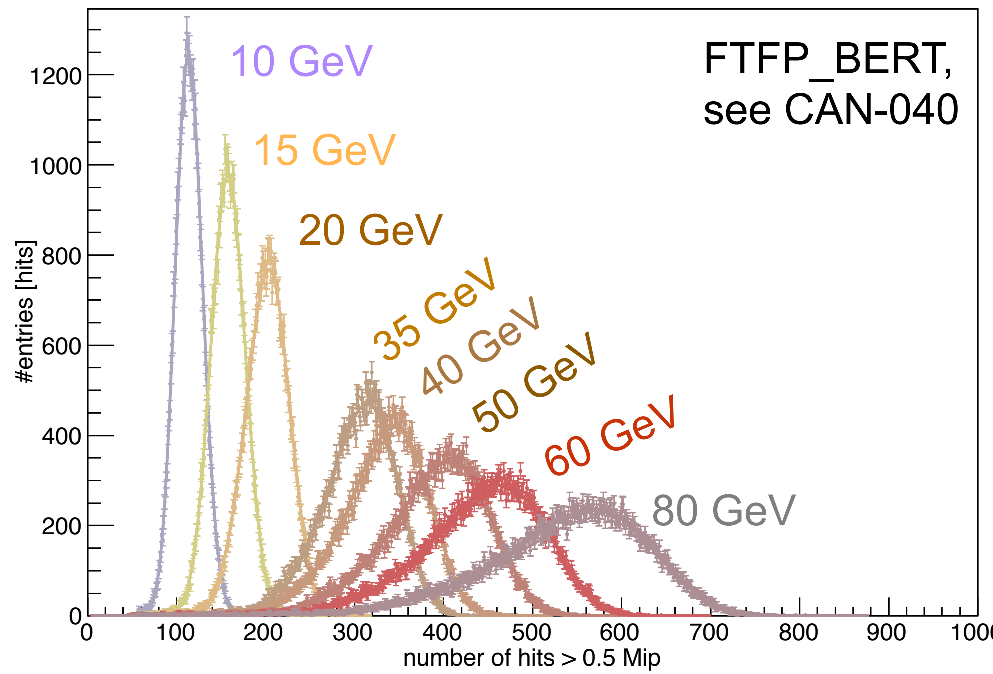
- After ShowerStart Cut ~50.000 of 100.000 events left
- nHit distributions fitted with Novosibirsk function

$$f(x) = A \cdot \exp\left(-0.5\left(\frac{\ln^2\left[1+\Lambda\cdot\tau\cdot(x-\mu)\right]}{\tau^2}+\tau^2\right)\right)$$

$$\Lambda \equiv \frac{\sin\left(\tau\cdot\sqrt{\ln 4}\right)}{\sigma\cdot\tau\cdot\sqrt{\ln 4}}$$

- Most probable value (response) taken from μ of fit

Number of hits above 0.5MIPs



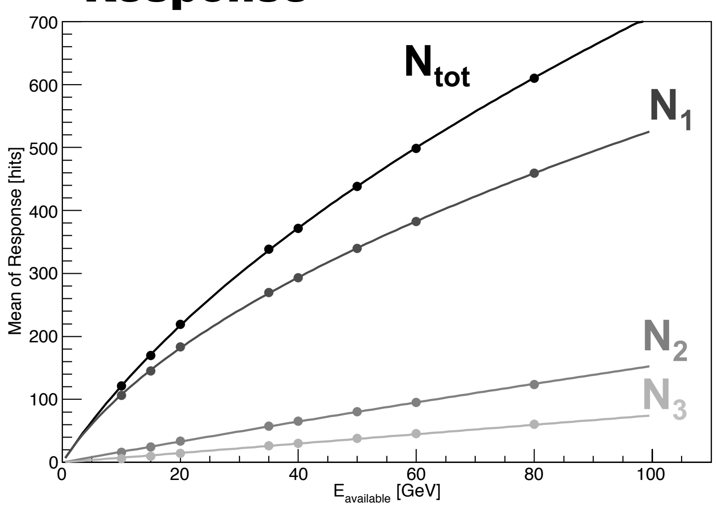
Multi threshold combination method

- Idea: distinguish between em and hadronic components of showers due to energy deposit

- Hits above thresholds:
  - **N_1** = 0.5 MIPs < hits < 5 MIPs
  - **N_2** = 5 MIPs < hits < 10 MIPs
  - **N_3** = hits > 10 MIPs
  - **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:

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

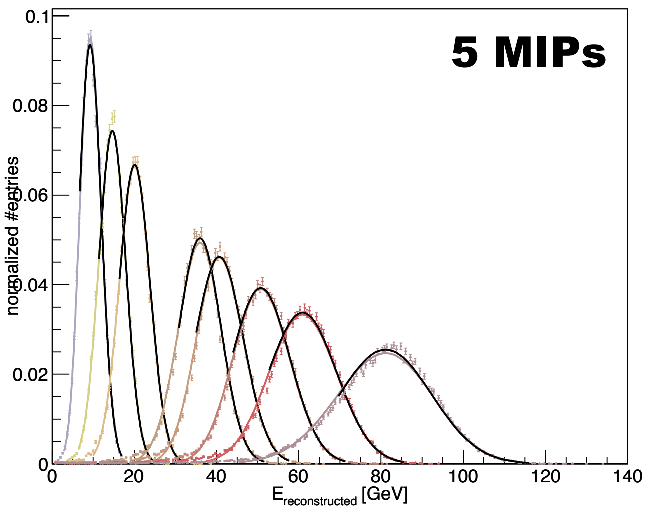
$$\alpha = a_1 + a_2 N_{tot} + a_3 N_{tot}^2,$$
$$\beta = b_1 + b_2 N_{tot} + b_3 N_{tot}^2,$$
$$\gamma = c_1 + c_2 N_{tot} + c_3 N_{tot}^2$$

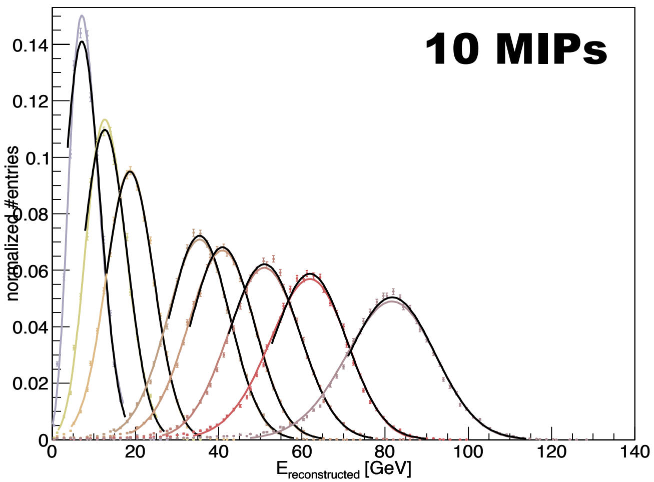
2. Parameter characterisation by minimization of:

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

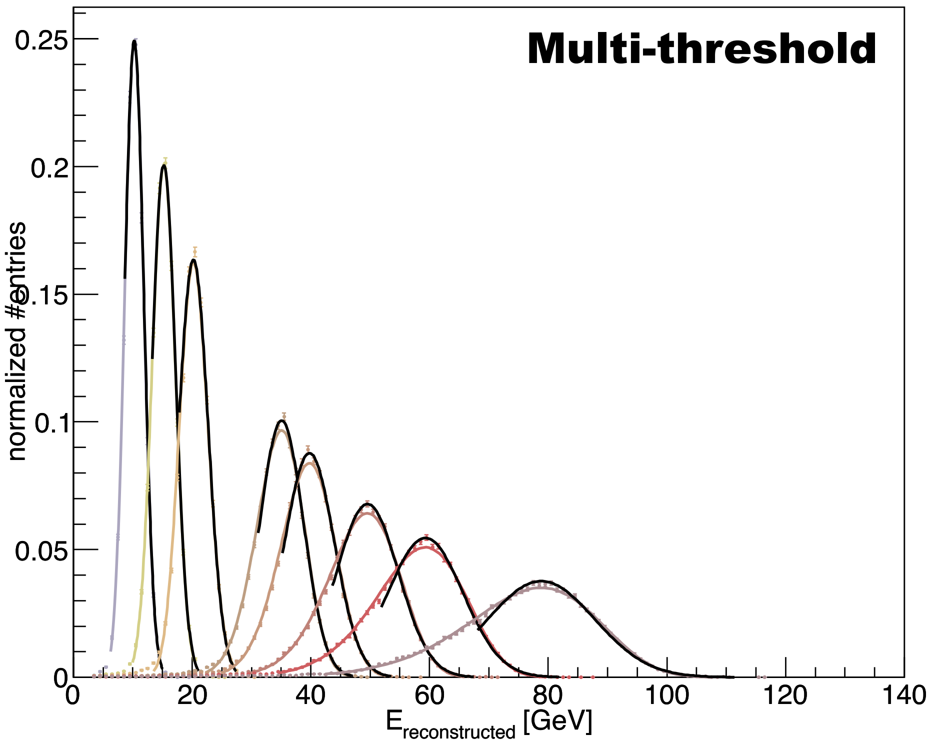
- α,β and γ are polynomial of N_{tot} thus give energy dependent weight to hits above different threshold

Reconstructed energy





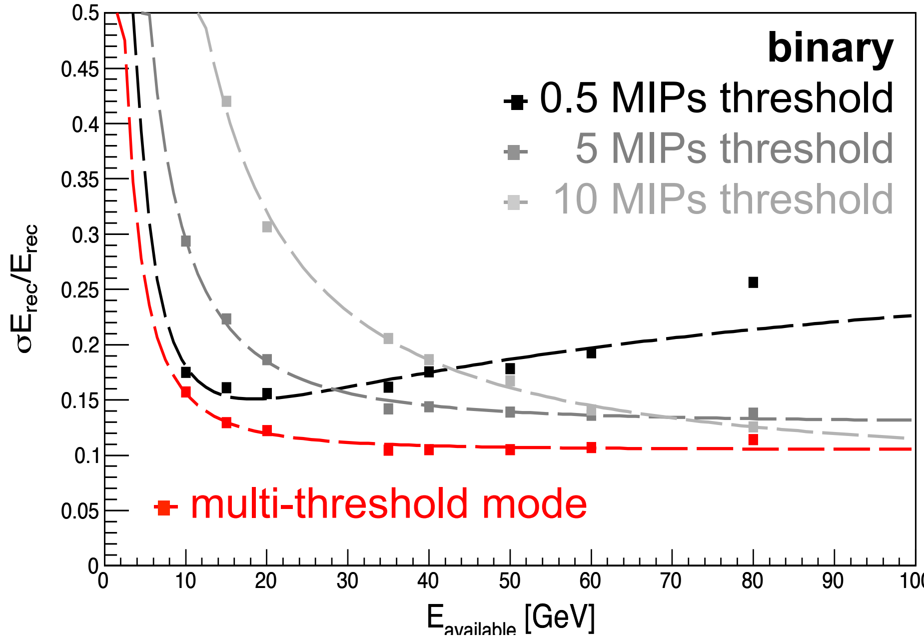
- Tails on left hand side due to leakage and limited granularity



- Fitted with Novosibirsk ➔ MPV, and width taken from Gaussian (fitted to -1/+3 σ)

Multi threshold versus binary mode

WORK IN PROGRESS



Resolution & Linearity

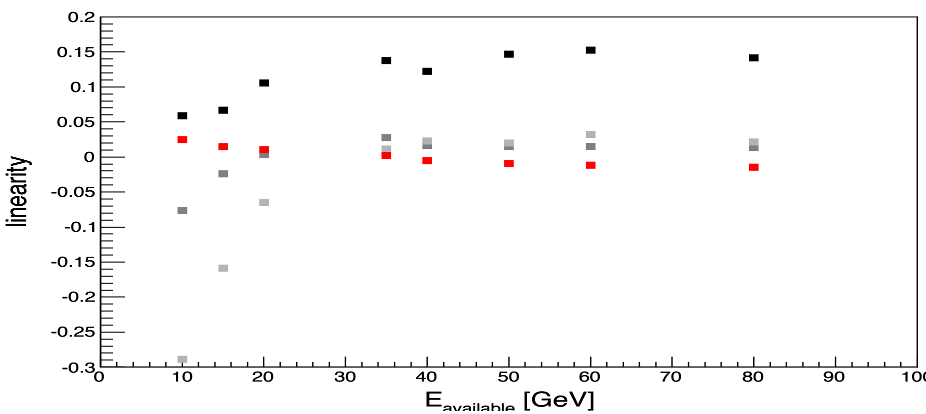
> Binary modes

- Lowest threshold best for low energies (< 25GeV)
- 10 MIPs threshold improves for high energies (> 70 GeV)
- Linearity best for 5 MIPs threshold, 0.5 MIPs linearity insufficient > 20 GeV, 10 MIPs insufficient < 30 GeV

> Multi-threshold mode

- Best resolution
- Best linearity

> Better than best AHCal mode?

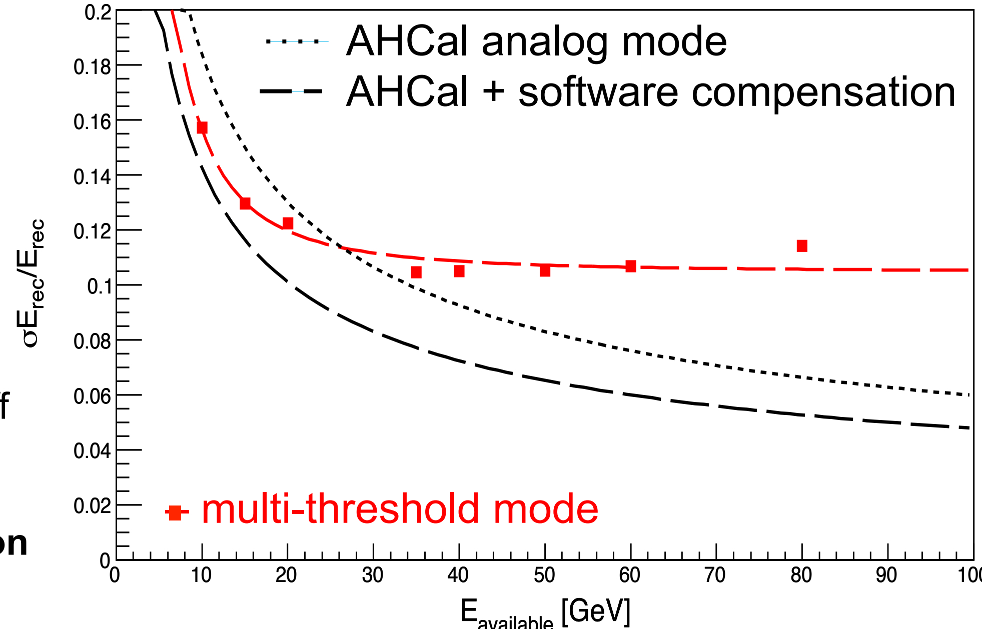


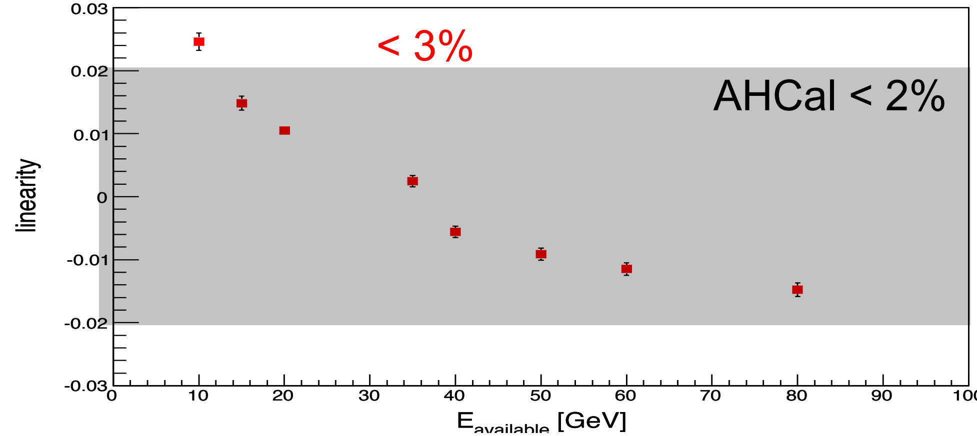
Multi threshold combination method

Resolution & Linearity

- **>** AHCal mode
  - ECal + HCal +TCMT information
- **>** AHCal + software compensation
  - Local 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
- **>** Multi-threshold mode achieves nearly AHCal + software compensation resolution < 15 GeV

WORK IN PROGRESS





Conclusions & Outlook

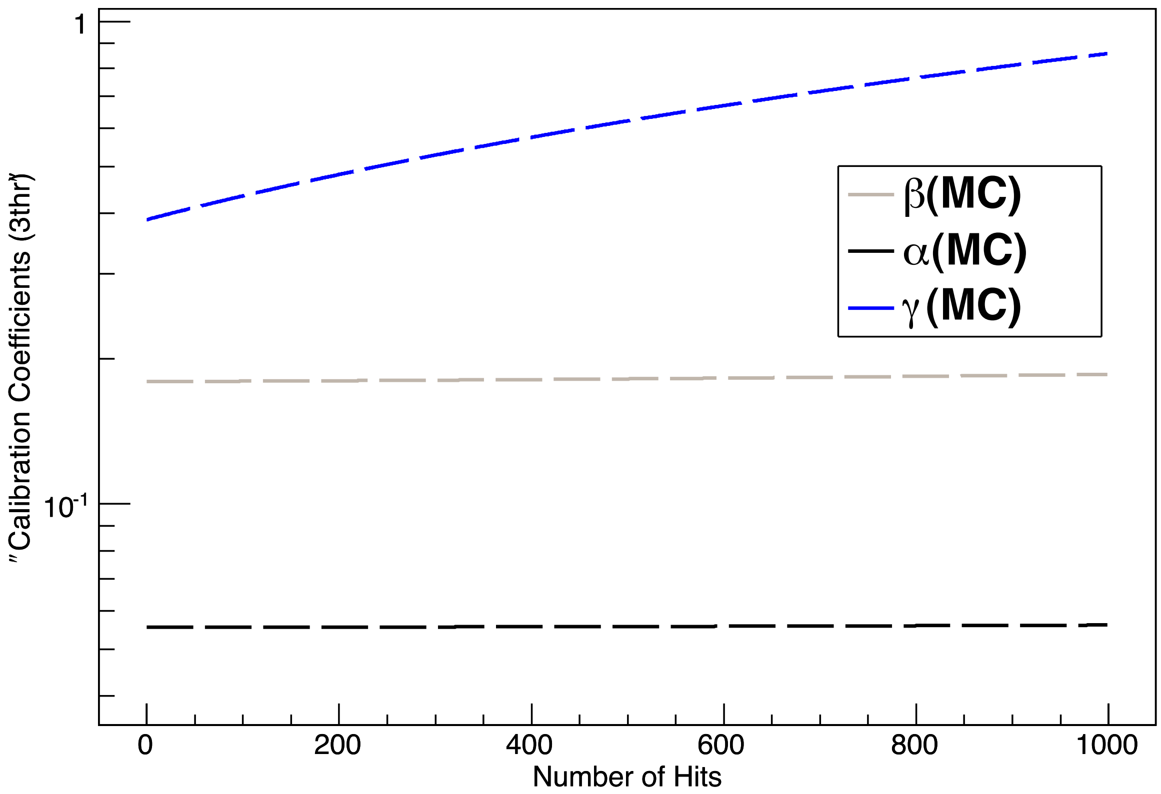
- For higher energies, AHCal shows best resolution especially with software compensation
- Semi-digital improves in comparison to digital readout

THINGS NEED TO BE DONE

- Data-MC comparison for TB Cern 2007
- Adding high energy TB data of W-AHCal Cern 2011
- Direct comparison with W-DHCal data CERN TB 2012
  - Calibration steps on data & simulation missing
  - Implementation of additional hit weighting method ("software compensation")

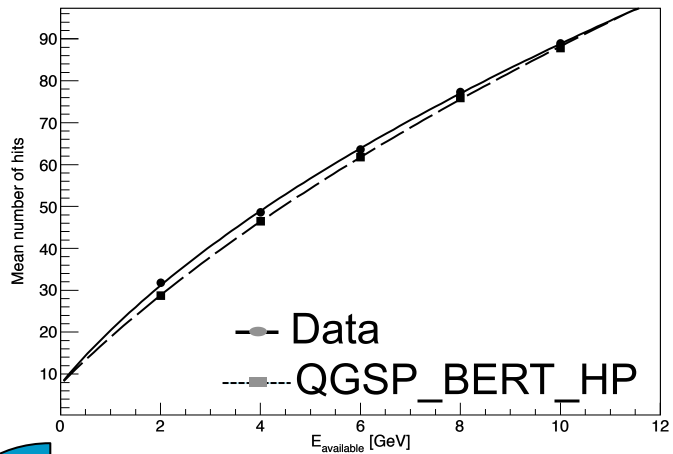
> Thank You for Your Attention!

Semi-digital calibration coefficients

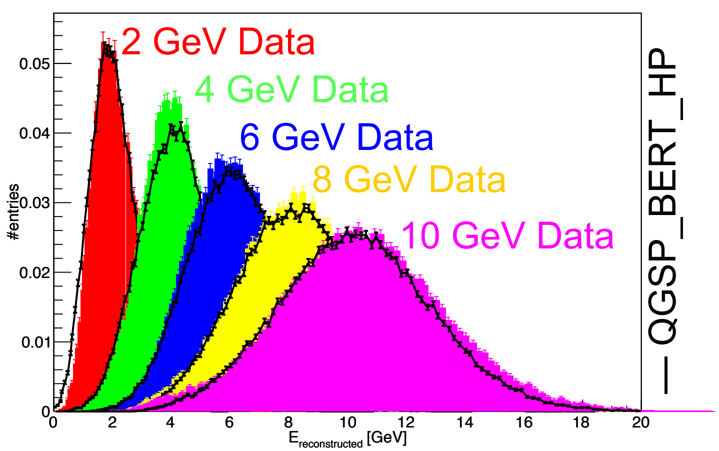


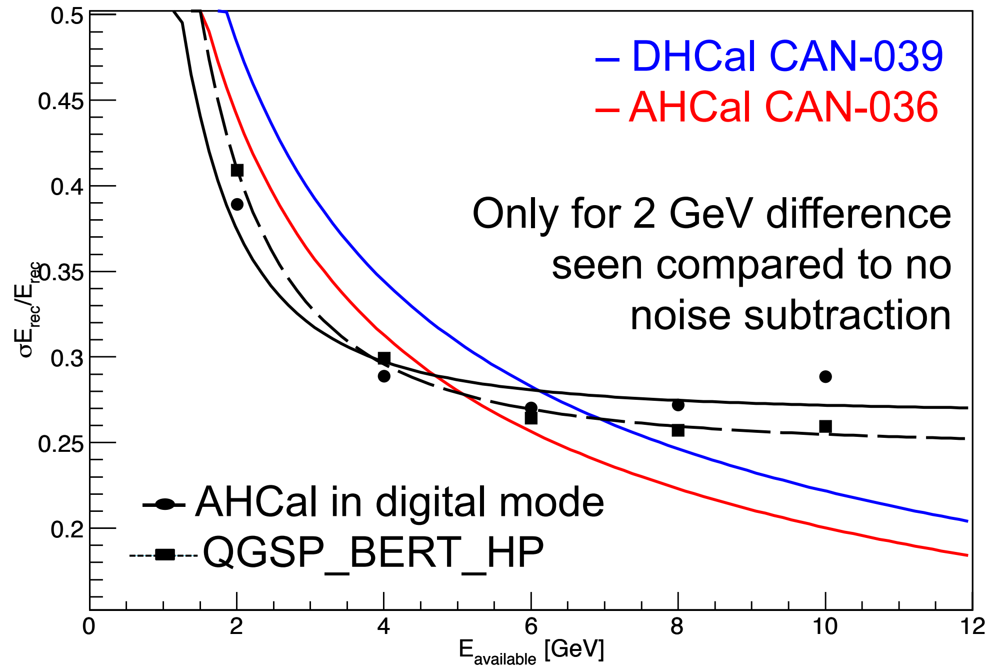
Low energy TB Cern noise included

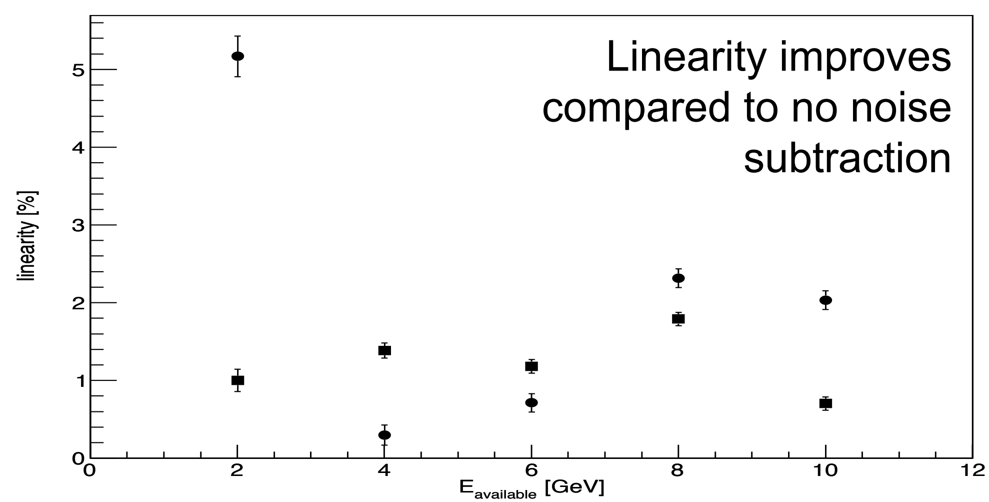
Noise of 7.6 hits



New parameters for linearization
➔ Reconstructed energy



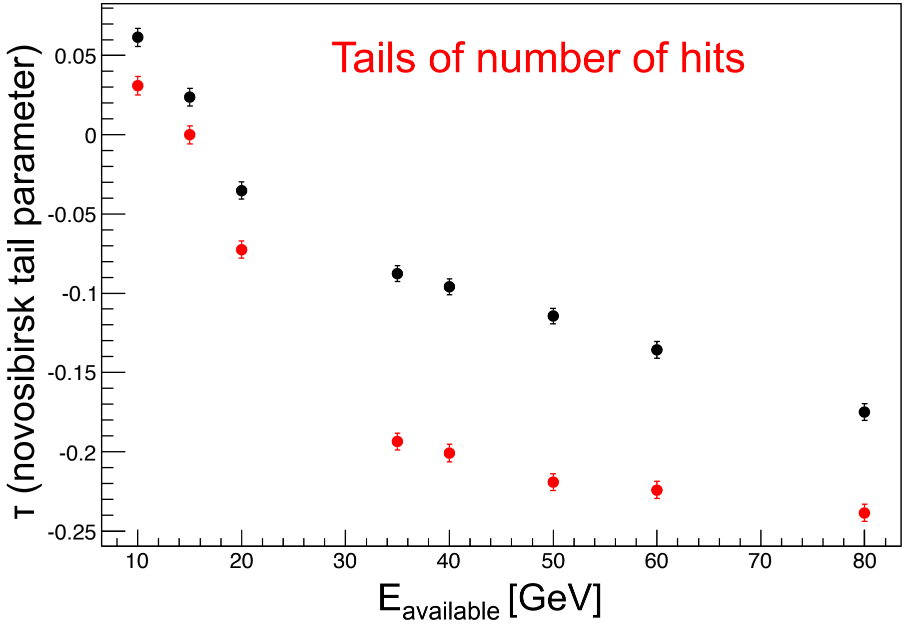




Reconstructed energy with&without leakage

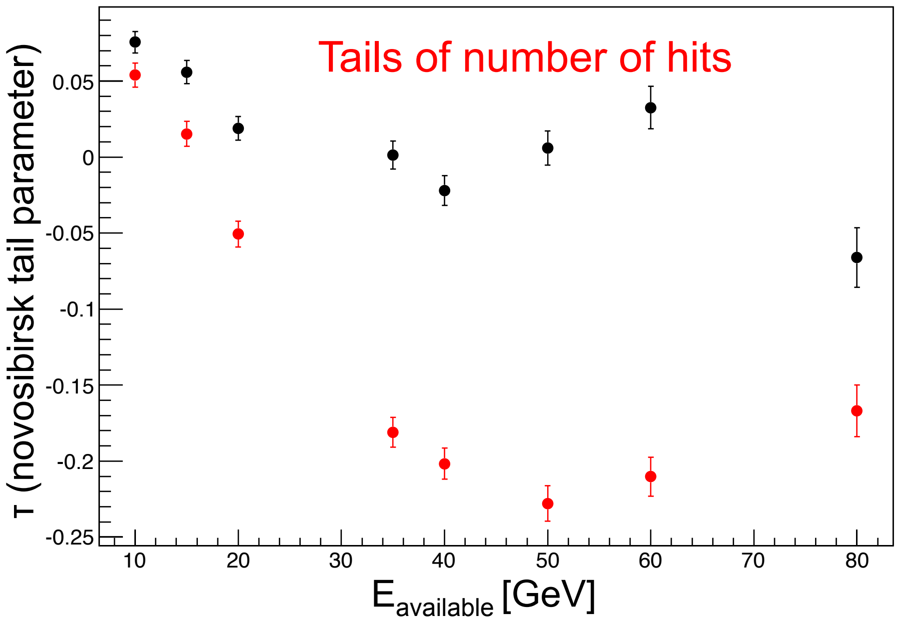
Normal pion selection

Tails of energy sum



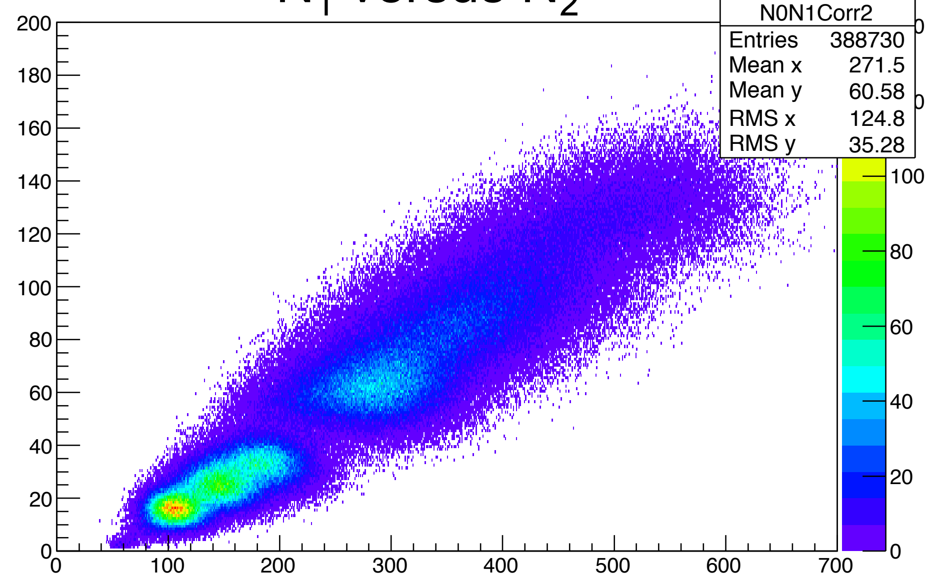
selection with hard leakage cut

Tails of energy sum

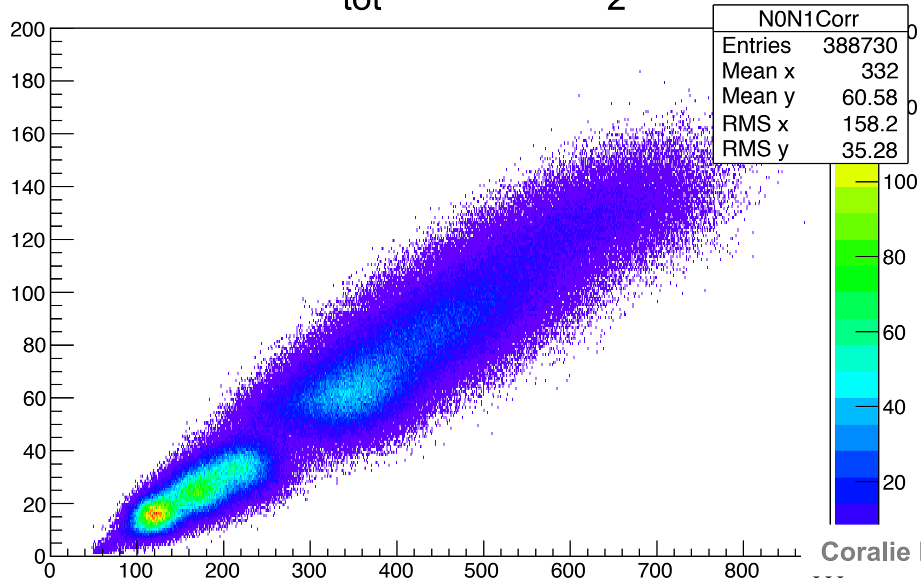


Correlation between hits above different thresholds

> N_1 versus N_2



> N_{tot} versus N_2



DHCal Data versus CAN-036

- Resolution fit parameters: $$resolution = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

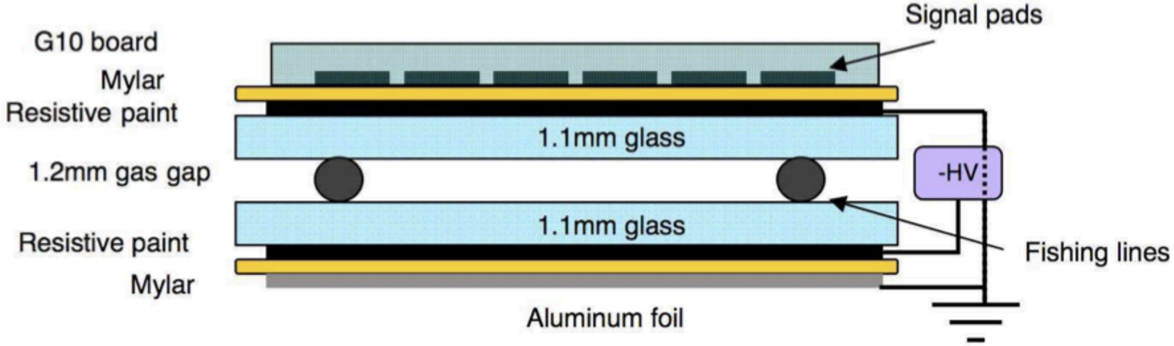
Low energy W-	Stochastic term a	Constant term b	Noise term c
AHCal in digital mode	25 ± 0.5	27.1 ± 0.1	0.071 (fixed)
AHCal paper	61.9 ± 1.0	4.2 ± 2.2	0.071 (fixed)
DHCal paper	68	5.4	0 (fixed)

High energy Fe-	Stochastic term a	Constant term b	Noise term c
AHCal in multi-thr mode	0.9 ± 0.3	11.6 ± 0.1	0.18 (fixed)
AHCal paper	57.6 ± 0.4	1.6 ± 0.3	0.18 (fixed)
AHCal + local software compensation paper	44.3 ± 0.3	1.8 ± 0.2	0.18 (fixed)

Calibration of physics prototype digital HCal

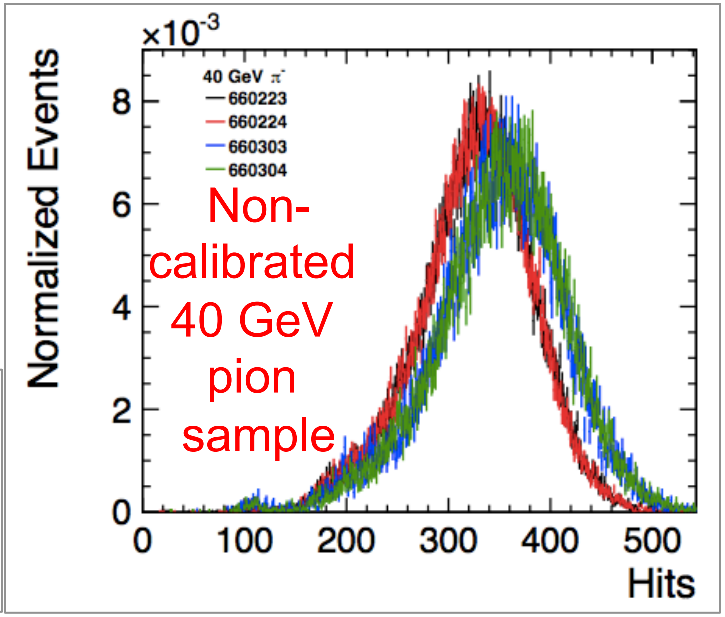
Burak Bilki *et al.* **"Environmental Dependence of the Performance of Resistive Plate Chambers"**, *arXiv:0911.1351*

- 54 RPC layer
- Main stack: 15 mm gaps with 12.85 mm cassettes + 2 mm copper and 2 mm steel plates
- 39 layer with 1 cm tungsten absorber
- 23.5 cm behind, TCMT (tail catcher / muon tracker) stack: 15 with steel absorber (first 8 with 2 cm steel plates, last 7 with 10 cm)



- 96 × 96 1x1 cm^2 pads with single threshold

Run-wise calibration needed to correct for temperature / pressure changes and layer-to-layer fluctuations



C.Grefe, **"Calibration of the W-DHCAL test beam"**, *LCWS Tokio 2013*

TB CERN 2007 – MC pion sample

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xTalk: 0.15

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$$\Lambda \equiv \frac{\sin\left(\tau\cdot\sqrt{\ln 4}\right)}{\sigma\cdot\tau\cdot\sqrt{\ln 4}}$$

- Most probable value (response) taken from μ of fit