Towards a comparison of the Analogue and Digital HCAL

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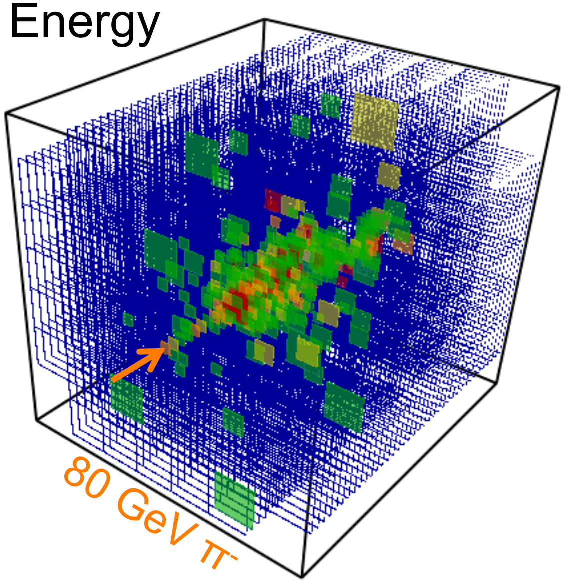
CALICE hadron calorimeters overview

- CALICE developed highly granular sampling hadron calorimeters based on scintillator tiles and RPCs (Resistive Plate Chambers)
  - With analogue, digital and semi-digital read-out

Analogue, 12bit readout of max. 3x3cm^2 tiles

- Deposited Energy

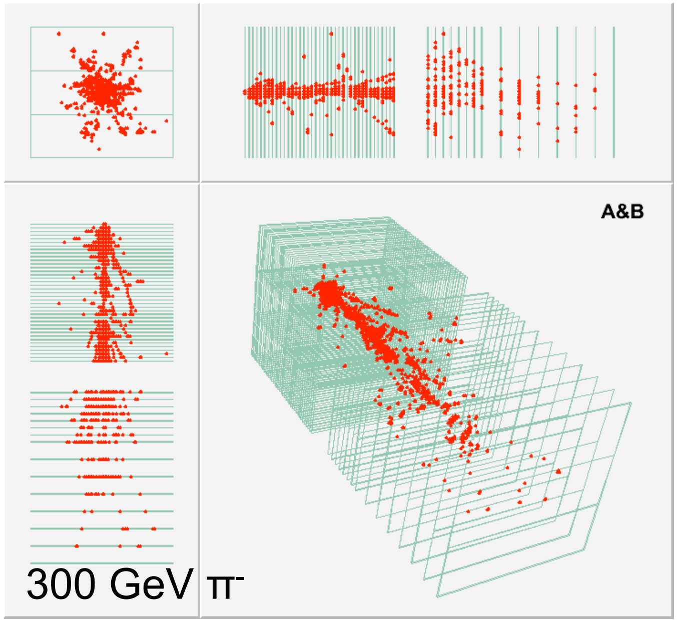
E_{Sum}



Digital, 1bit readout of 1x1cm^2 pads

- Number of hits ~ particle energy

N_{hits}



Calice Analysis Note CAN-039

+ Semi-digital, 2bit readout

- Number of hits above each of 3 thresholds

Idea

Study differences (medium, read-out, granularity) & their impact on energy resolution

- Read-out & energy reconstruction
  - with AHCAL, (semi-) digital energy reconstruction is possible
- Active medium & Granularity
  - validate simulation, to study AHCAL in $1x1cm^2$ granularity

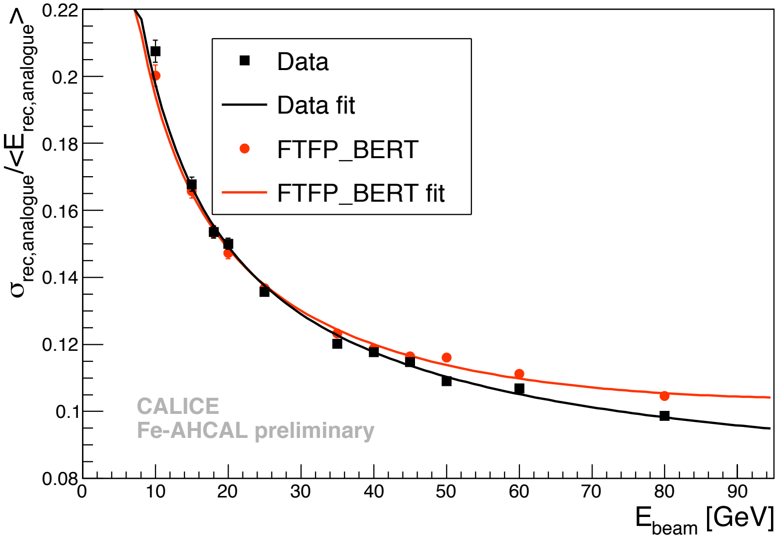
> Until now studied for Fe absorbers, but of course interesting for W absorbers as well

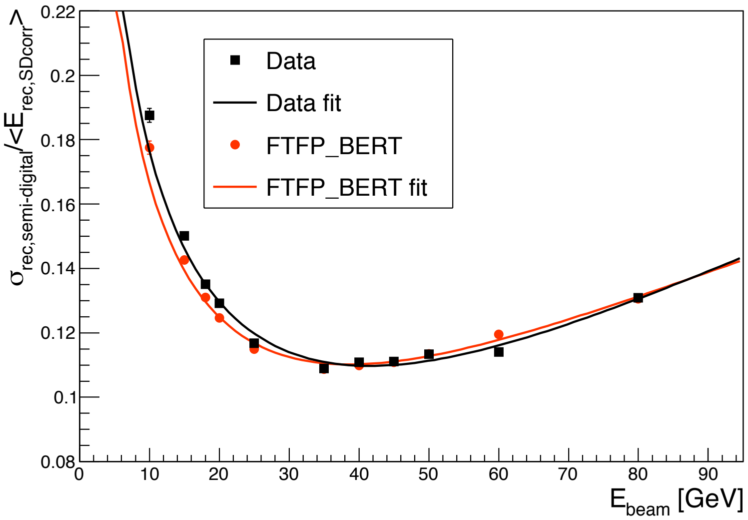
Contents

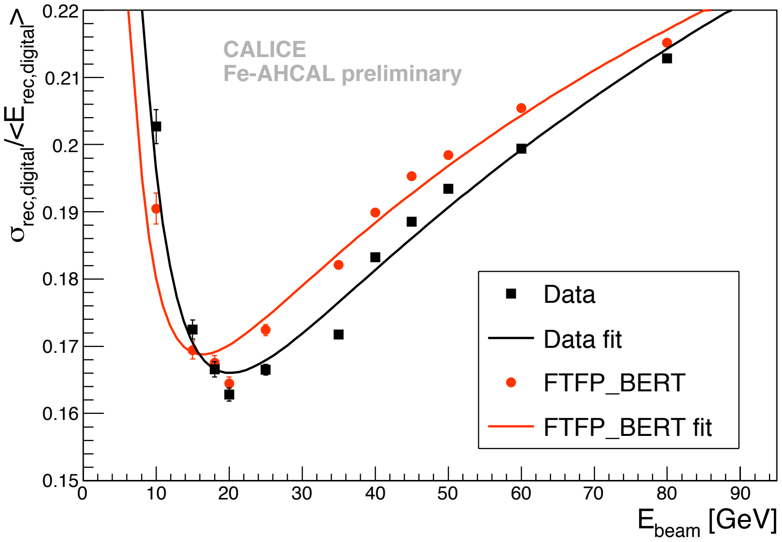
- AHCAL simulation validation & AHCAL in 1x1cm^2 granularity
- Fe-DHCAL status
  - Geant4 & Mokka model
  - Digitisation / RPC response simulation
  - Data calibration
  - First results from Digitiser tuning
- Outlook

Results from the CALICE Analysis Note 049

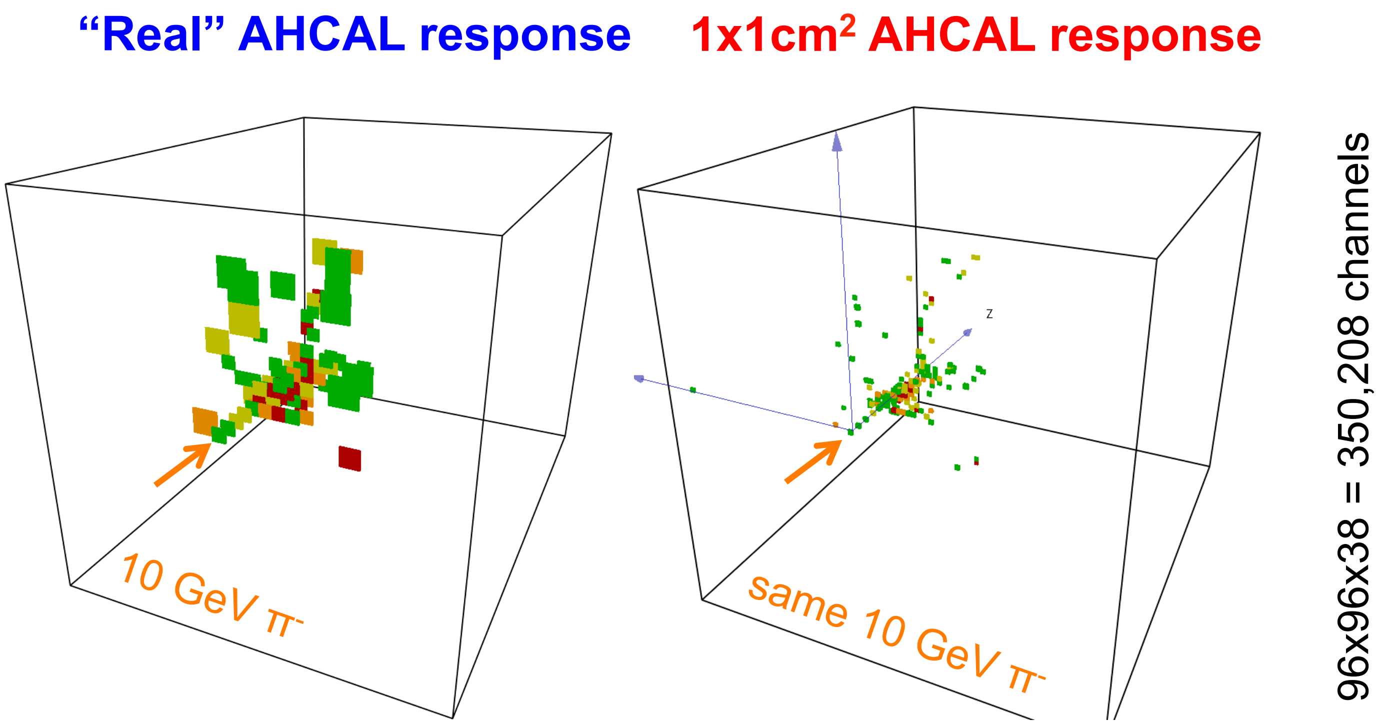
- Study of digital energy reconstruction procedures for the Fe-AHCAL
  - Analogue, digital & semi-digital
  - Digital capabilities limited by granularity
  - Semi-digital energy reconstruction makes up partially for digital limitations (similar to Software Compensation Techniques)
- Validated the simulation





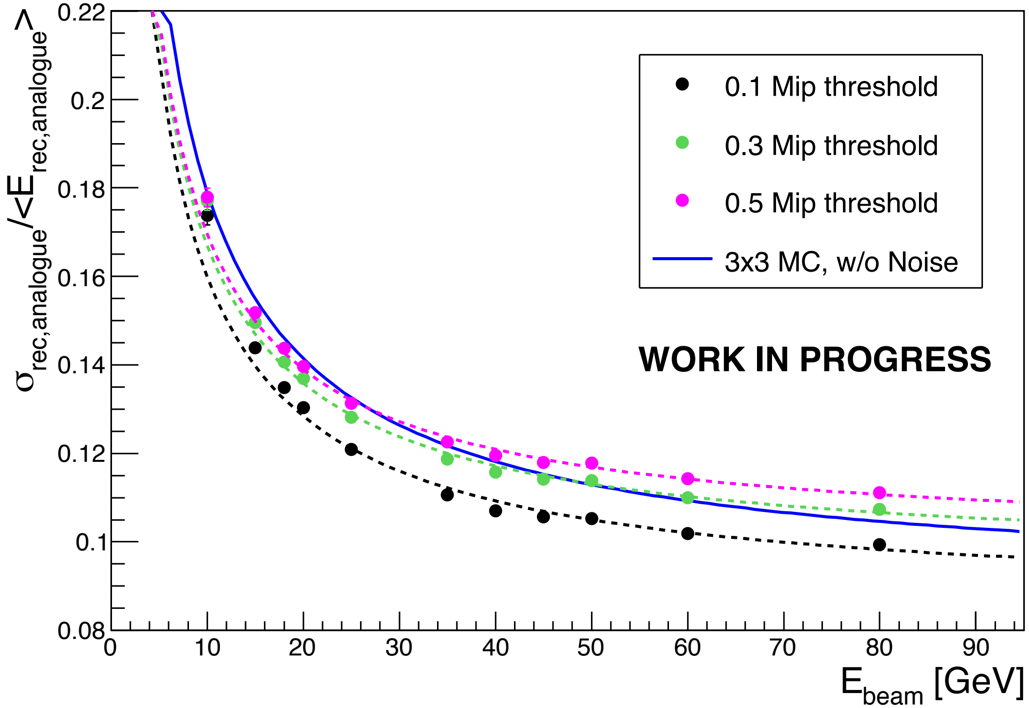


AHCAL with DHCAL granularity



- Both simulations include SiPM response and its calibration + optical crosstalk
- Remaining differences:
  - No cell-wise calibration&correction constants for 1x1cm^2 (default values from database used)
  - No noise runs for 1x1cm^2 AHCAL, but noise not relevant for newest SiPMs

1x1cm² AHCAL resolution



3x3cm²

$$\frac{\sigma_{rec}}{\langle E_{rec}\rangle} = \frac{49.14}{\sqrt{E_{beam}[GeV]}} \oplus 8.903$$

1x1cm²

$$\frac{\sigma_{rec}}{\langle E_{rec}\rangle} = \frac{43.45 \pm 0.34}{\sqrt{E_{beam}[GeV]}} \oplus 9.95 \pm 0.03$$

$$\frac{\sigma_{rec}}{\langle E_{rec}\rangle} = \frac{43.46 \pm 0.33}{\sqrt{E_{beam}[GeV]}} \oplus 9.49 \pm 0.03$$

$$\frac{\sigma_{rec}}{\langle E_{rec}\rangle} = \frac{42.67 \pm 0.30}{\sqrt{E_{beam}[GeV]}} \oplus 8.59 \pm 0.03$$

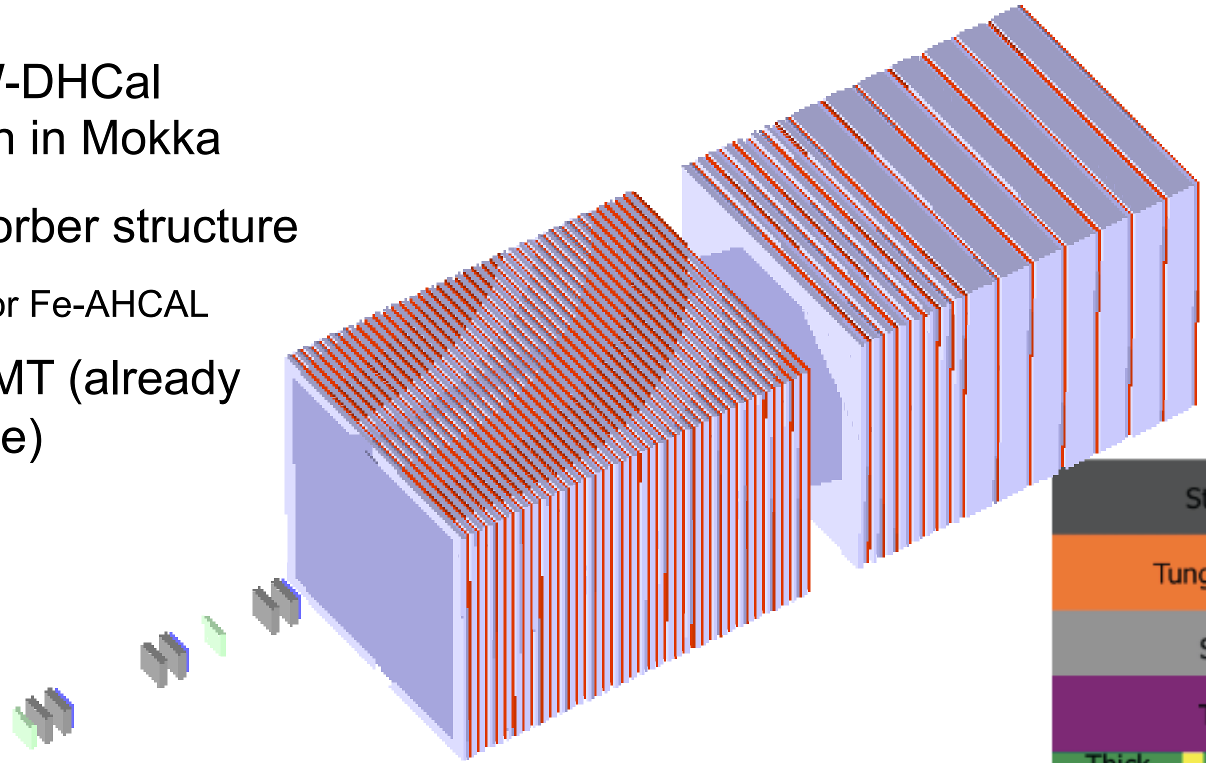
- Differences in resolution due to threshold effects
- For small energies 1x1cm² granularity beneficial
- For higher energies, difference depends on threshold
- Higher granularity decreases stochastic term
- **Investigation of digital reconstruction is still ongoing**

Status of DHCAL

- No published comparison of data & MC
- DHCAL funding in US terminated by DOE
- Person power very limited also for WDHCAL effort
- Use common analysis tools as far as possible

Simulating Fe-DHCAL tb @ Fermilab geometry

- Started with W-DHCal implementation in Mokka
- Replaced absorber structure
  - Same stack for Fe-AHCAL
- Use same TCMT (already consisting of Fe)

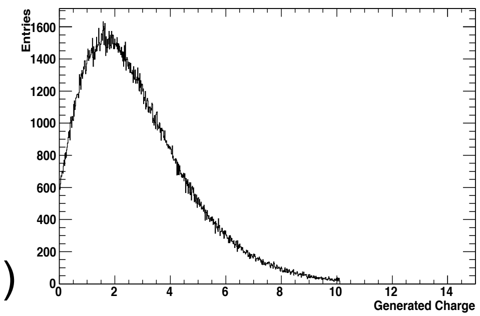


- Sensitive detector volume RPCs
  - Gas mixture (94.5% Freon(Dichlorodifluoromethane), 5% C_4H_{10}(Butan), 0.5% SF_6(Sulfur hexafluoride))
  - Cassette: fishing lines, steel sheets, mylar, glass, boards, asics, resistive layer, aluminum frame

RPC response simulation

- Output of Geant4+Mokka are raw points of ionisation
- Next step simulation of RPC charge avalanche & read-out

1. Exponential $\mathbf{d_{cut}}$ 1.4mm, only one avalanche
2. Generating charge randomly (following parametrization from data taken with analog RPC

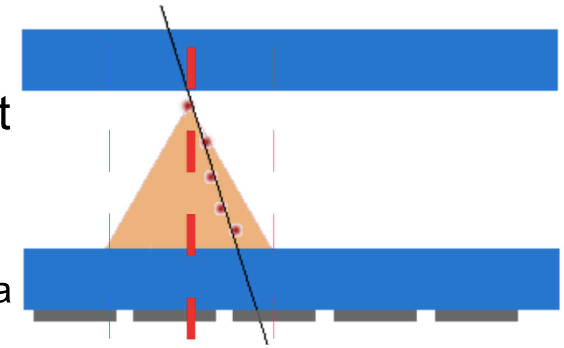


3. Allowing shift Q = Q_{tot} - $\mathbf{Q_0}$ (0.8pC)
4. Model radial charge distribution in RPC with RPCSim5 model as double-Gaussian

$$f(r) = R \cdot e^{-\frac{r^2}{(2\sigma_1)^2}} + (1-R)e^{-\frac{r^2}{(2\sigma_2)^2}}$$

ChargeSpreadParameters: $\boldsymbol{\sigma_1}$=0.7 $\boldsymbol{\sigma_2}$=7 **R**=0.18 within 4cm

5. Threshold: **TT** 0.15pC



To match simulation to data, charge reduced on boundaries, charge is spread only within RPC modules

For tuning of $\boldsymbol{\sigma_1}$, $\boldsymbol{\sigma_2}$, R, TT and $\mathbf{Q_0}$ use muons

Tuning of d_{cut} use electrons

Matching simulation to data

- In simulations every RPC is in same condition
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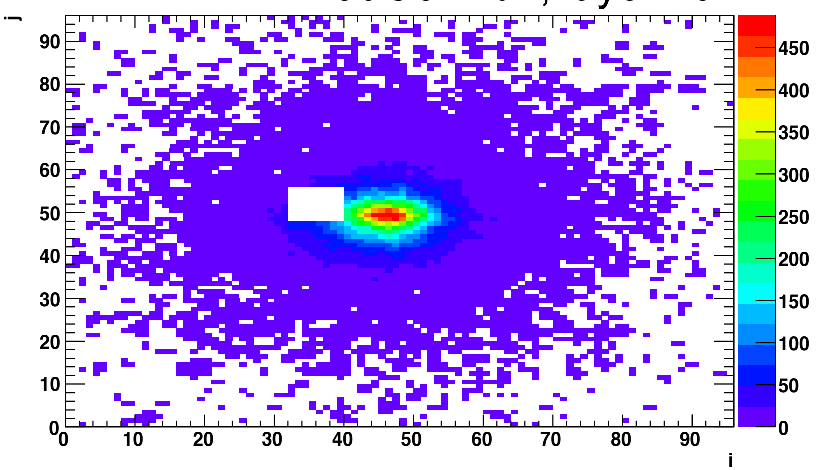
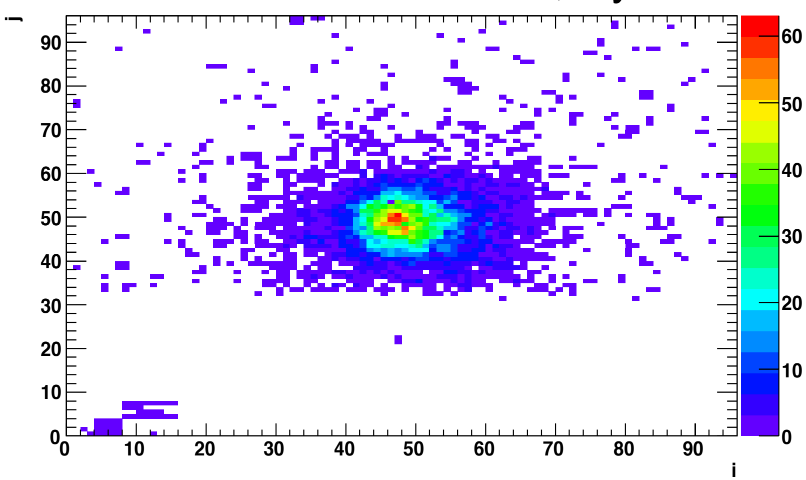
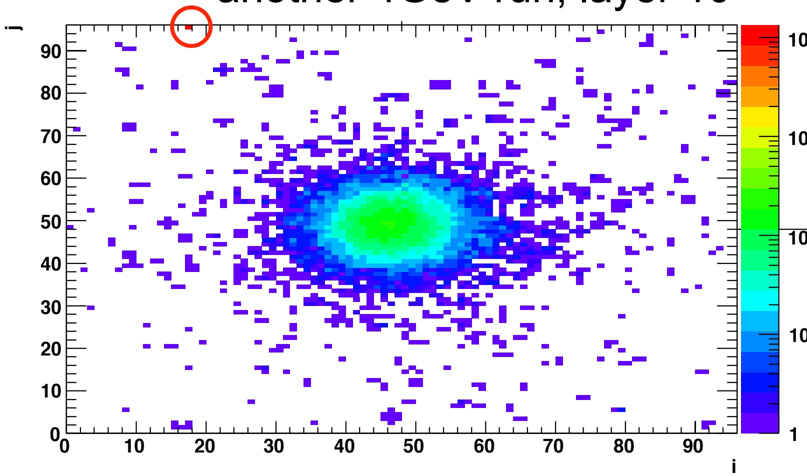
50GeV run, layer 25



4GeV run, layer 12



another 4GeV run, layer 10



- List of dead Asics & dead/missing front-end boards
- + list of hot cells

→ Excluded from data & simulation runs

Matching simulation to data

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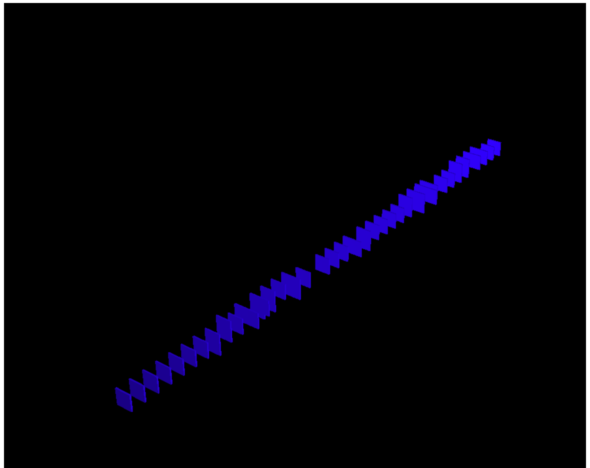
→ Correct data for HV differences, temperature/gas pressure variations by

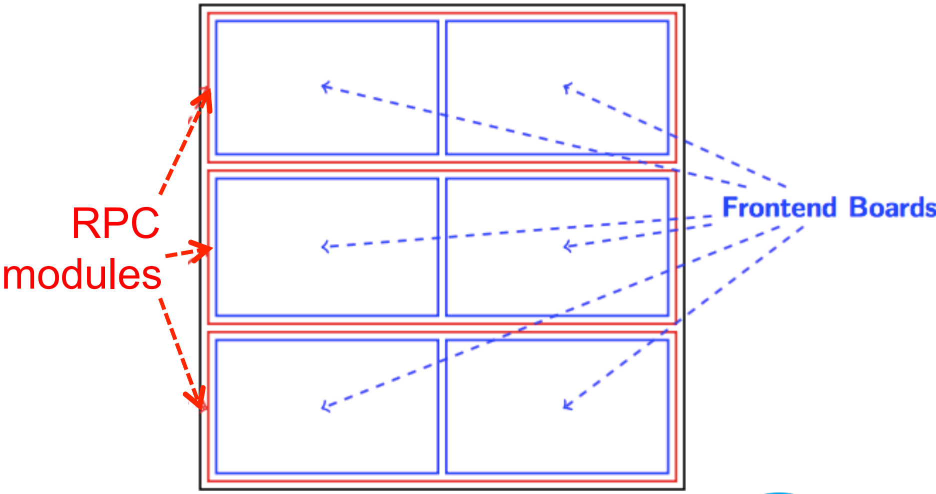
  - **Full calibration**, weights each hit dependent on the local mu and eff of its RPC



Example 32 GeV muon track

$$N_{hits,calib} = \sum_{i,j}^{layer,RPC} hit_{i,j} \cdot \frac{\varepsilon_0 \mu_0}{\varepsilon_{i,j} \mu_{i,j}}$$

DHCAL layer



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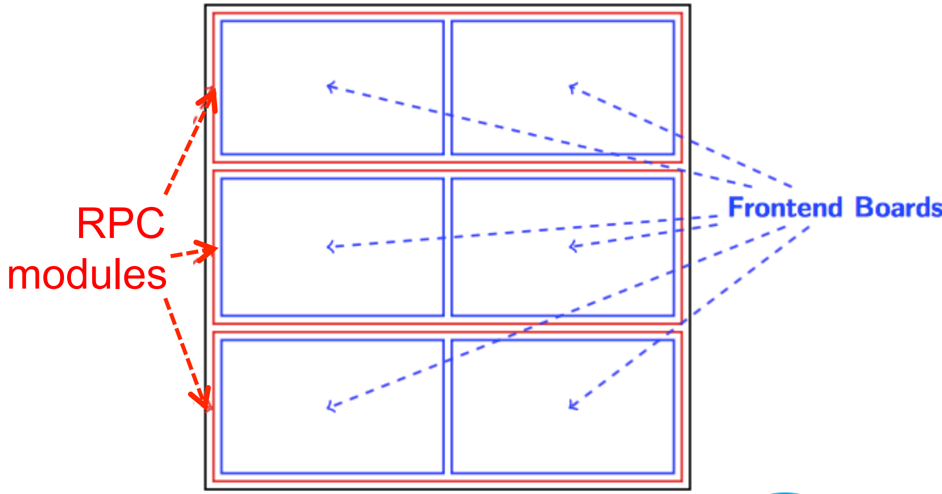
→ Found some discrepancies in old calibration values

→ Apply "in situ" calibration for each RPC

DHCAL layer



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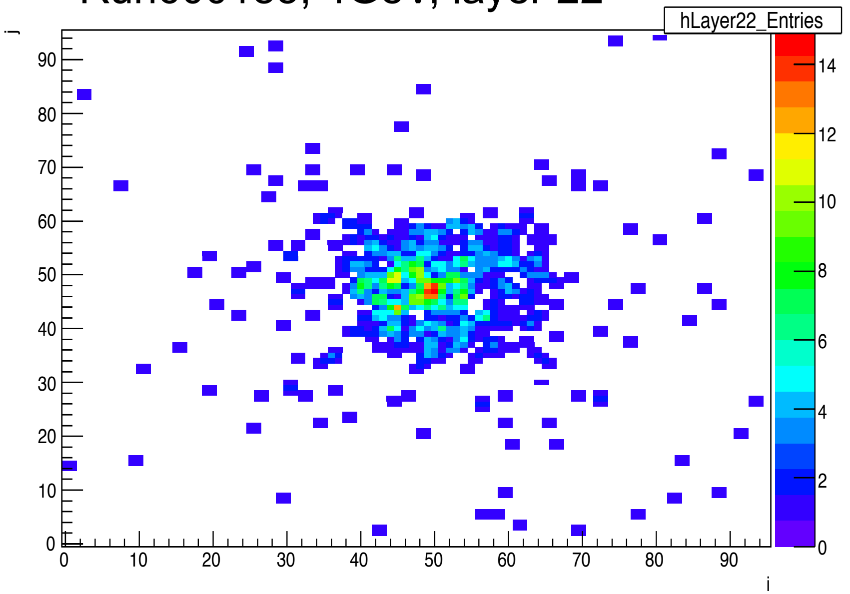
  - Used clustering algorithm for MIP like tracks in data runs (tracks before and after point of interest)

Run600185, 4GeV, layer 22



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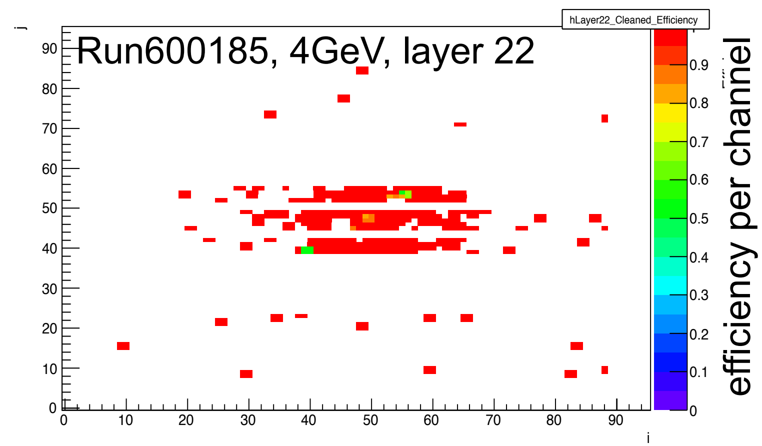
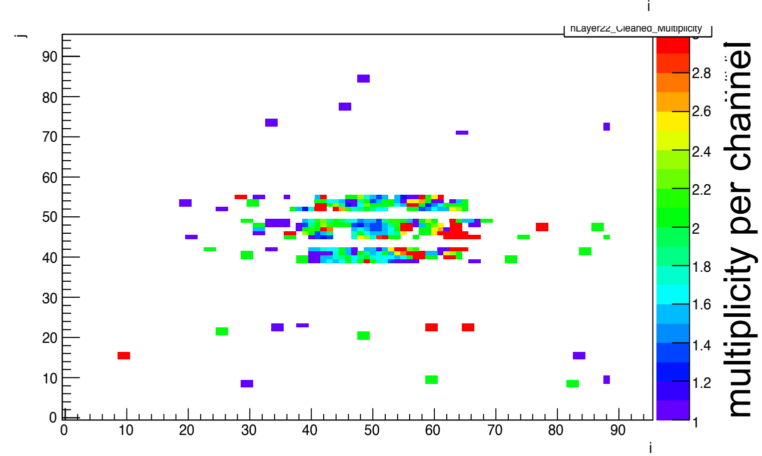
→ Found some discrepancies in old calibration values

→ Apply “in situ” calibration for each RPC

  - Used clustering algorithm for MIP like tracks in data runs (tracks before and after point of interest)
  - Extracted efficiency and multiplicity for each RPC in cleaned region (don’t want to correct for inefficiencies due to fishing lines ect., this is included in simulation)
  - in case of not sufficient statistics, less than 500 entries per module, use εμ from different module of layer (usually the middle one)



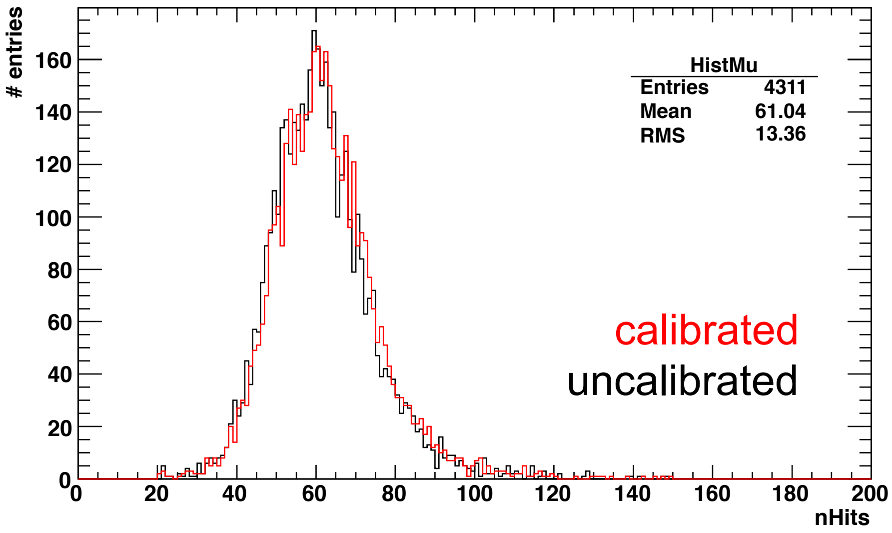


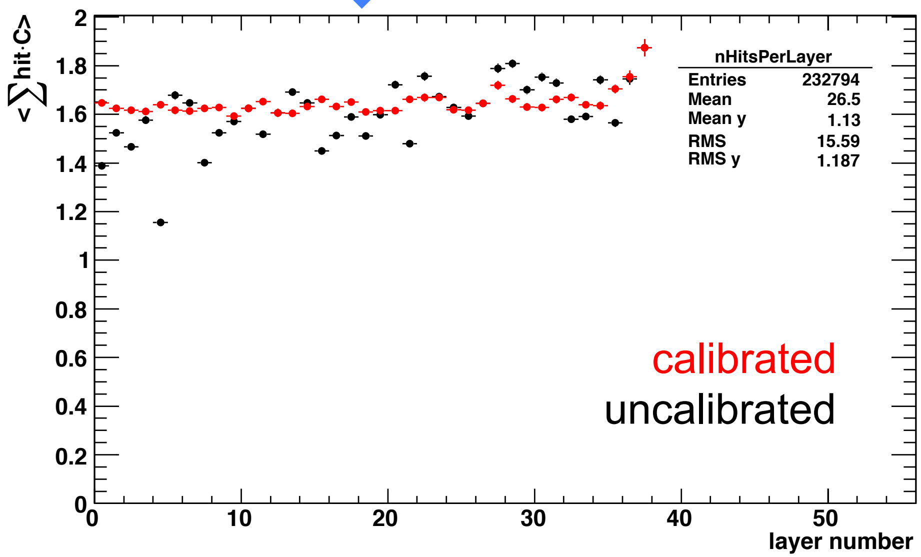
Calibration validation with muons

- Muon selected by Muon Tagger + topological PID
  - → No identified interaction Layer
  - → Average hit density < 2 hits per layer
  - → Barycenter > layer 15

Input for digitizer tuning

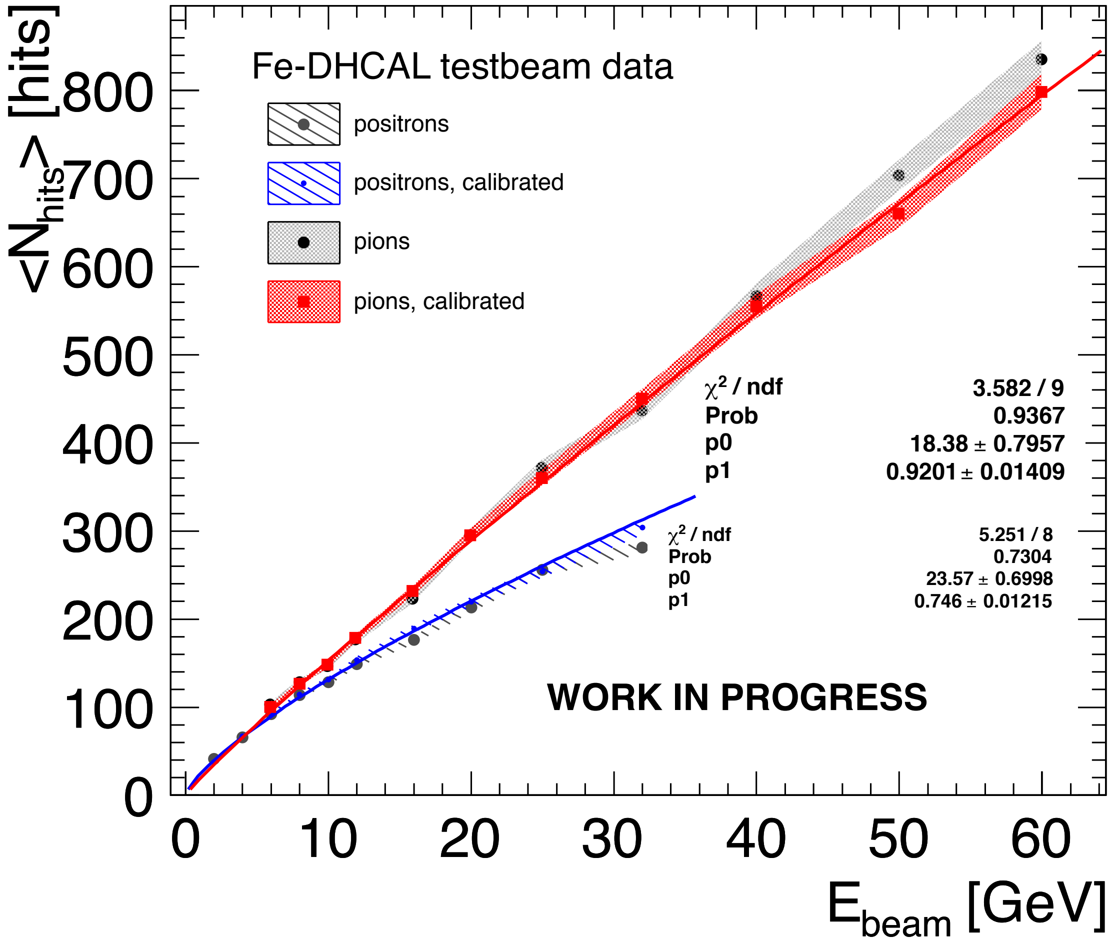
32GeV muons





- Nicely corrected response to $\varepsilon_0 = 0.97, \mu_0 = 1.69$

Fe-DHCAL data "fully calibrated"



Pion response extracted from Gaussian fits within +2 -1.5 sigma and the positron response from fits within +/-2 sigma

- Slight straightening seen
- Ready to tune digitisation parameters

Quick reminder: RPC response simulation

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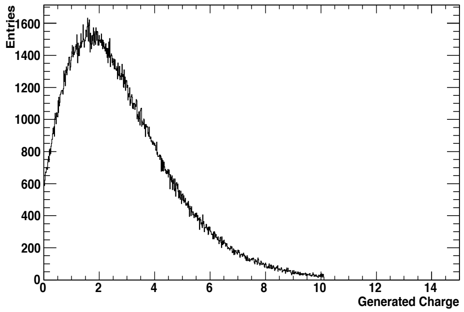

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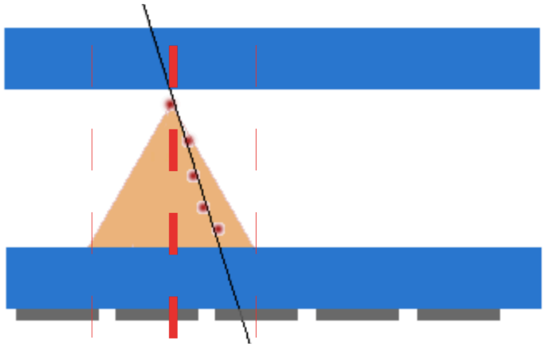

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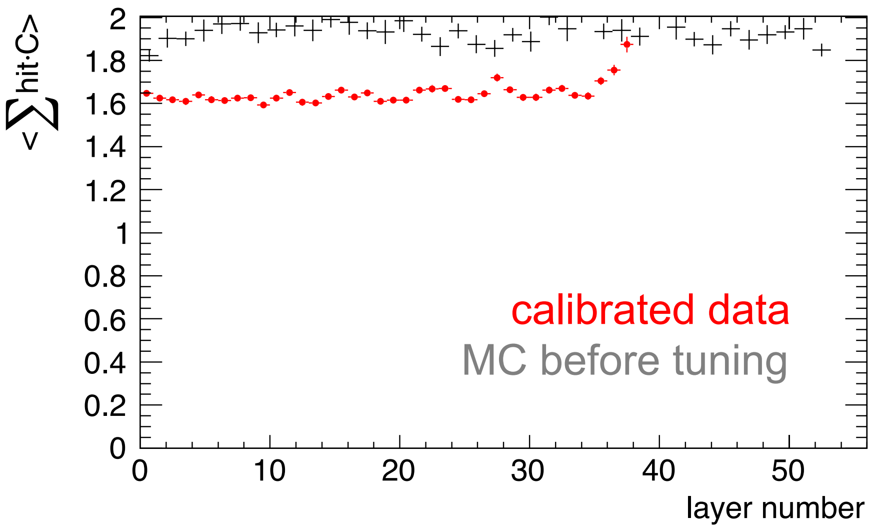
Tuning of d_{cut} use electrons

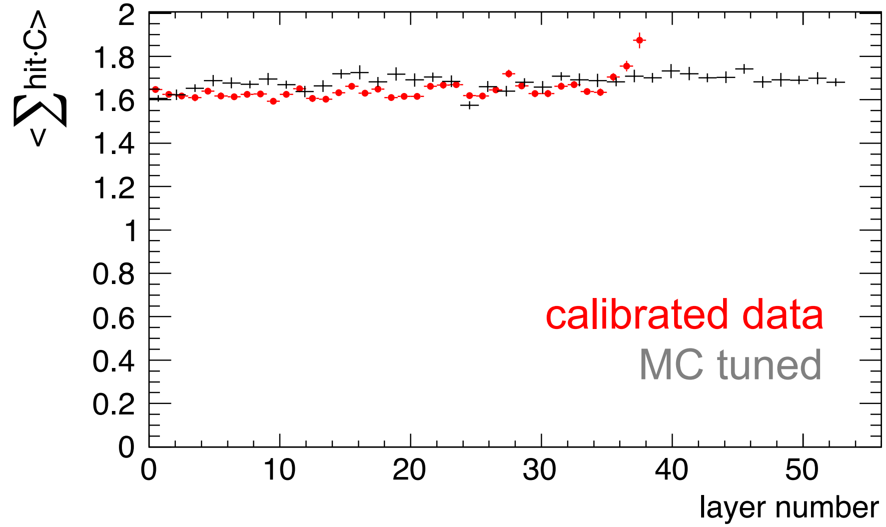
First results of digitiser tuning

- Starting parameters from earlier efforts
- 5 different values for each of 5 parameters
- Run all possible 3125 permutations
- Get best fit by chi2 test of <#hits>
- Results show range needs to be extended for some parameters

$$\sigma_0 = 1.0mm$$
$$\sigma_1 = 9mm$$
$$r = 0.14$$
$$TT = 0.2pC$$
$$Q_0 = 1.0pC$$
$$d_{cut} = 1.4mm(fixed)$$

32GeV muons





- Before going on with tuning…

Outlook

1. Improve Mokka implementation:
   - Add upstream material, like @Fermilab tb
   - Add beam profile
2. Rerun digitiser tuning also for d_{cut} with electrons
3. Validate pion simulation

4. Compare with Fe-AHCAL in digital mode

Many thanks to W-DHCAL group, Christian & Thibault!

Backup

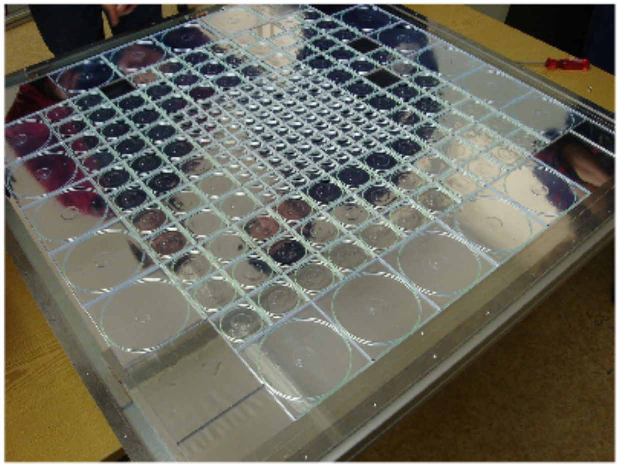
> Fe-DHCAL TB data is converted to slcio, run list following CAN-042

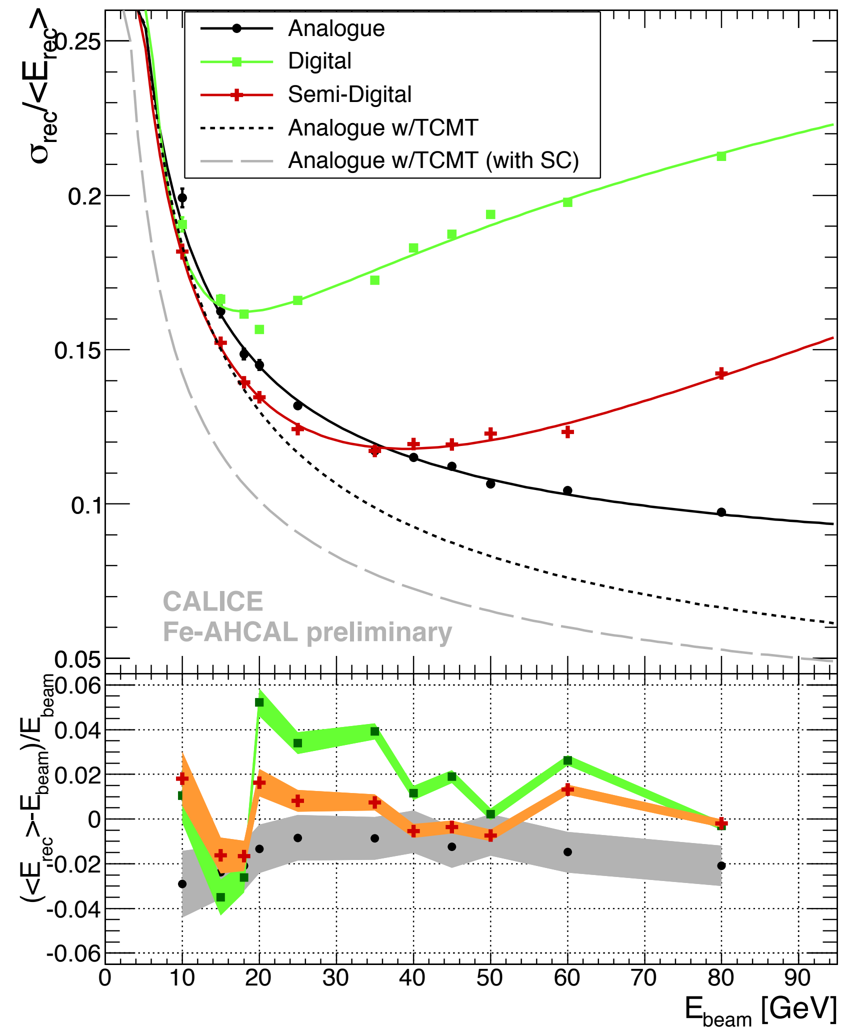
- E2=(600139 600140 600143 600145 600147 600148 600149 600150 600152 600153 600154 600155 600156 600157 600158 600159 600160 600161 600162 600163 600164 600165 600166)
- E4=(600089 600091 600092 600176 600177 600178 600179 600180 600181 600185 600186)
- E6=(600187 600193 600194 600195 600196)
- E8=(600082 600083 600084 600197 600198 600202 600203 600204)
- E10=(600205 600206 600207 600208 600209 600210 600211 600212)
- E12=(600075 600076 600077 600079 600080)
- E16=(600063 600064 600065 600069 600070)
- E20=(600054 600055 600058 600059 600062)
- E25=(600049 600050 600052 600053)
- E32=(600036 600038 600040 600043 600044 600045 600048)
- E40=(630125 630126 630128 630129 630130 630131 630133 630134)
- E50=(630137 630139 630141 630142 630144 630145)
- E60=(630146 630147 630148 630152 630153 630154)
- **in total 101 runs**

Reminder: Results from the CALICE Analysis Note 049

- Study of digital energy reconstruction procedures for the Fe-AHCAL

Scintillator tile sampling HCAL with SiPM 12bit read-out e/π=1.18

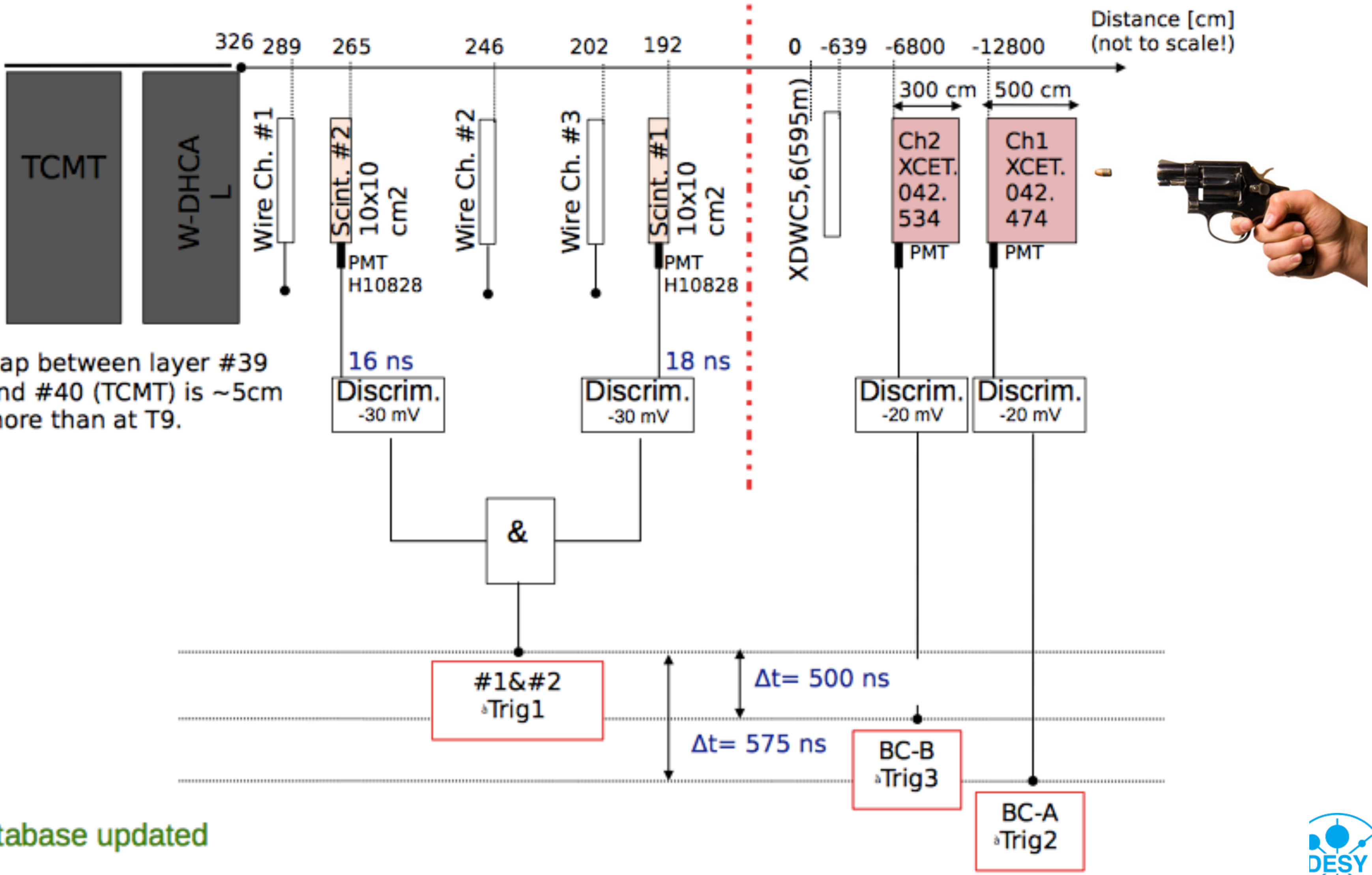




  - Analogue, digital & semi-digital
  - Digital capabilities limited by granularity
  - Semi-digital energy reconstruction makes up partially for digital limitations (similar to Software Compensation Techniques)
- Validated the simulation

Backup

CALICE W-DHCAL Trigger Setup in CERN-SPS-H8C



Gap between layer #39 and #40 (TCMT) is ~5cm more than at T9.

Database updated

Backup

- Comparison of old and new calibration factors
- Statistical effects