EPICAL2 analysis status

Hiroki Yokoyama

23/06/2021
Energy calibration by longitudinal shower profile
Energy calibration (fine tuning) with TB data

- apply pre-calibration parameters from cosmic muons measurement
- relative gain between LHS and RHS chips are corrected to have the same response
- recalculate lateral density profile applying LHS/RHS amplitude correction
  - per-chip density -> per-layer density
- inter-layer calibration by longitudinal profile
  - average number of cluster = sum of cluster density profile
  - 21 gain parameters (layer 0, 12 and 23 are fixed) are tuned using 11 run conditions (energies, beam directions)
  - exclude two chips (in layer 20 and 21) for $\rho^0$ calculation, $c^0=1$ for opposite chip
  - $f^{exp}$ is given by third spline interpolation of longitudinal $<N_{hit}>$ profile
  - data points used for $\chi^2$ evaluation:
    - $2 \leq \text{layer} \leq 22$ (forward dir. runs)
    - $1 \leq \text{layer} \leq 21$ (backward dir. runs)

\[
\rho_{i,h}^0(r) = \frac{1}{N_{\text{event}}} \sum_{\text{event}} \frac{n_{i,h}^{\text{hit}}(r)}{n_{i,h}^{\text{pixel}}(r)} \times \frac{1}{S_{\text{pixel}}} 
\]

\[
c_i^0 = \frac{2 \times \int_{R_0}^{R_1} \rho_{i,RHS}^0(r) 2\pi r \, dr + \int_{R_0}^{R_1} \rho_{i,LHS}^0(r) 2\pi r \, dr}{\int_{R_0}^{R_1} \rho_{i,RHS}^0(r) 2\pi r \, dr + \int_{R_0}^{R_1} \rho_{i,LHS}^0(r) 2\pi r \, dr}
\]

\[
c_i^{0,\text{all}} = (\delta c_i^{0,\text{all}})^2 \times \sum_k c_i^{0,k} \cdot (\delta c_i^{0,k})^{-2} = \sum_k (\delta c_i^{0,k})^{-2}
\]

\[
\rho_i^1(r) = \frac{1}{N_{\text{event}}} \sum_{\text{event}} \frac{c_i^{0,\text{all}} \cdot n_{i,LHS}^{\text{hit}} + c_i^{0,\text{all}} \cdot n_{i,RHS}^{\text{hit}}}{n_{i,LHS}^{\text{pixel}} + n_{i,RHS}^{\text{pixel}}} \times \frac{1}{S_{\text{pixel}}}
\]

\[
\langle N_{i,h}^{\text{hit}} \rangle = \int_0^R \rho_i^1(r) 2\pi r \, dr
\]

\[
\chi^2(l) = \sum_k \left( \frac{\langle N_{i,k}^{\text{hit}} \rangle - f_k^{exp}(l)}{\delta \langle N_{i,k}^{\text{hit}} \rangle} \right)^2
\]

Update layer gain that gives largest difference
Repeat until all gain parameters converge

$R_0 = 5 \text{ mm, } R_1 = 15 \text{ mm, } R = 25 \text{ mm}$
validity of the assumption:
\( \text{layerX (forward dir.)} = \text{layer(24-X) (backward dir.)} \)

-5% ~ +15% difference
- reject this idea
inter-layer calibration ($N_{\text{clus}}$)
**inter-layer calibration ($N_{clus}$)**

**before**

![Before calibration graph]

**after**

![After calibration graph]

**comparison**

![Comparison graph]
inter-layer calibration ($N_{\text{clus}}$) without pre-calibration

Comparison before and after calibration for different energy ranges.
**inter-layer calibration ($N_{clus}$) without pre-calibration**

![Comparison of $N_{clus}$ before and after inter-layer calibration](image)
inter-layer calibration ($N_{hit}$)

Comparison of hits before and after calibration for different energy thresholds.
inter-layer calibration ($N_{\text{hit}}$)

comparison

before 1.0 GeV  after 1.0 GeV  before 1.0 GeV(180°)  after 1.0 GeV(180°)
before 2.0 GeV  after 2.0 GeV  before 2.0 GeV(180°)  after 2.0 GeV(180°)
before 3.0 GeV  after 3.0 GeV  before 3.0 GeV(180°)  after 3.0 GeV(180°)
before 4.0 GeV  after 4.0 GeV  before 4.0 GeV(180°)  after 4.0 GeV(180°)
before 5.0 GeV  after 5.0 GeV  before 5.0 GeV(180°)  after 5.0 GeV(180°)
before 5.8 GeV  after 5.8 GeV

before 1.0 GeV(180°)  after 1.0 GeV(180°)
before 2.0 GeV(180°)  after 2.0 GeV(180°)
before 3.0 GeV(180°)  after 3.0 GeV(180°)
before 4.0 GeV(180°)  after 4.0 GeV(180°)
before 5.0 GeV(180°)  after 5.0 GeV(180°)
before 5.8 GeV(180°)  after 5.8 GeV(180°)
**inter-layer calibration (N_{hit}) without pre-calibration**

![Graph depicting inter-layer calibration](image)

The graph shows the distribution of hits (N_{hit}) before and after calibration for different energies (1.0 GeV, 2.0 GeV, 3.0 GeV, 4.0 GeV, 5.0 GeV, and 5.8 GeV) across various layers. The comparison highlights the changes in hit distribution before and after calibration.
inter-layer calibration ($N_{\text{hit}}$) without pre-calibration

**Comparison**

Before and after inter-layer calibration ($N_{\text{hit}}$) without pre-calibration.
Energy measurement linearity and resolution
total $N_{\text{clus.}}$ measurement
total $N_{\text{clus.}}$ measurement (without calibration)
total $N_{\text{hit}}$ measurement
total $N_{hit}$ measurement (without calibration)
Any improvement by the cluster selection?

- energy resolution by hit measurement
  - (left) remove clusters whose size $\geq n_{\text{cut}}$
  - (right) take cluster-size of large-size clusters as $n_{\text{cut}}$

![Graphs showing energy resolution vs. cluster-size cut](image-url)
lateral shower profile
lateral cluster density (1)

- energy dependence for the same layer
lateral cluster density (2)

- energy dependence for the same layer
**lateral cluster density (3)**

- layer dependence for the same beam energy
lateral hit density (1)

- energy dependence for the same layer
lateral hit density (2)

- energy dependence for the same layer
**lateral hit density (3)**

- layer dependence for the same beam energy

![Graphs showing lateral hit density for different beam energies and layers.](image)
longitudinal shower profile
longitudinal shower profile

![Graph showing the longitudinal shower profile with various energy levels: E = 5.8 GeV, E = 5.0 GeV, E = 4.0 GeV, E = 3.0 GeV, E = 2.0 GeV, and E = 1.0 GeV. The graphs display the number of hits (N_h) and the number of clusters (N_c) as a function of depth (X_0). The plots are labeled with the energy levels and the fit range [1.5, 20.0].]
number of clusters within the ring

E = 5.0 GeV

- 0 ≤ r < 25 (mm)
- 0 ≤ r < 5 (mm)
- 5 ≤ r < 10 (mm)
- 10 ≤ r < 15 (mm)
- 15 ≤ r < 20 (mm)

E = 3.0 GeV

- 0 ≤ r < 25 (mm)
- 0 ≤ r < 5 (mm)
- 5 ≤ r < 10 (mm)
- 10 ≤ r < 15 (mm)
- 15 ≤ r < 20 (mm)
number of hits within the ring

\[
E = 5.0 \text{ GeV}
\]

- \(0 \leq r < 25 \text{ (mm)}\)
- \(0 \leq r < 5 \text{ (mm)}\)
- \(5 \leq r < 10 \text{ (mm)}\)
- \(10 \leq r < 15 \text{ (mm)}\)
- \(15 \leq r < 20 \text{ (mm)}\)

\[
E = 3.0 \text{ GeV}
\]

- \(0 \leq r < 25 \text{ (mm)}\)
- \(0 \leq r < 5 \text{ (mm)}\)
- \(5 \leq r < 10 \text{ (mm)}\)
- \(10 \leq r < 15 \text{ (mm)}\)
- \(15 \leq r < 20 \text{ (mm)}\)
longitudinal shower profile

- bit larger for angled runs

5 GeV

\[ N_{\text{hit}} \]

5 GeV

\[ N_{\text{hit}} \]

depth \((X_0)\)

depth \((X_0)\)
Longitudinal shower profile

- bit larger for angled runs

![Graph showing longitudinal shower profile for 3 GeV particles with different angles and depths.]

- $\theta = 0^\circ$
- $\theta = 2^\circ$
- $\theta = 10^\circ$
- $\theta = 20^\circ$
- $\theta = 180^\circ$
- $\theta = 0^\circ$ (e$^+$)

$0 \leq r < 25$ (mm)
fit range [1.5, 11.5]
longitudinal shower profile

- bit larger for angled runs

![Graphs showing longitudinal shower profile for different angles with depth (X₀) on the x-axis and N hit on the y-axis. The graphs compare the number of hits for different angles (θ) and show the fit range [1.5, 11.5] GeV.](image-url)
shower maximum
Average cluster size
lateral cluster size profile (1)

- energy dependence for the same layer
lateral cluster size profile (2)

energy dependence for the same layer
lateral cluster size profile (3)

Layer dependence for the same beam energy