```
  }
  // hand energies to cluster
  pCluster->setEInSamples(samEnergies);
```

Note that the vector with energies is appropriately sized without explicite knowledge of the numerical values of the `CaloSampling::CaloSample` enumerator. Nevertheless this storage model somewhat relies on these values representing a continously running index starting at 0 for optimized storage of these energies in the `CaloCluster` object (not too sparse).

`void CaloCluster::setEtaInSamples(const std::vector<double>& rEtas)`

Visibility .... public
Interface(s) .... `CaloCluster::setEtaInSamples(rEtas)`
Implementation(s) .... `CaloCluster::setEtaInSamples(rEtas)`

Variable	*Type*	*Comment*
`rEtas`	`std::vector<double>&`	reference to a non-modifiable vector of ηs

Sets the ηs of all contributing samplings in a cluster. The structure of `rEtas` is as discussed in the `CaloCluster::setEInSamples(...)` documentation on page 52 above.

`void CaloCluster::setPhiInSamples(const std::vector<double>& rPhis)`

Visibility .... public
Interface(s) .... `CaloCluster::setPhiInSamples(rPhis)`
Implementation(s) .... `CaloCluster::setPhiInSamples(rPhis)`

Variable	*Type*	*Comment*
`rPhis`	`std::vector<double>&`	reference to a non-modifiable vector of φs

Sets the φs of all contributing samplings in a cluster. The structure of `rPhis` is expected as in described in the `CaloCluster::setEInSamples(...)` documentation on page 52 above.

`const CaloCluster::moments_map& CaloCluster::moments()`

Visibility .... public
Interface(s) .... `CaloCluster::moments()`
Implementation(s) .... `CaloCluster::moments()`
Data source(s) .... `CaloCluster::m_moments`

Returns a reference to the non-modifiable store for `ClusterMoments`. This store is presently organized a map with `CaloClusterMoment::MomentType` key[IX] and a number storing the actual moment. The available moments have been introduced by S. Menke. The following documentation has been directly extracted from [2].

Figure B.1 shows the principal geometric variables used to calculate the cluster moments. The basic variables are the cluster center-of-gravity $\vec{c}$, the principal shower axis $\vec{s}$, and the cell location $\vec{x}_i$.

[IX] this enumerator is actually translated into an `int` for technical reasons related to persistency.

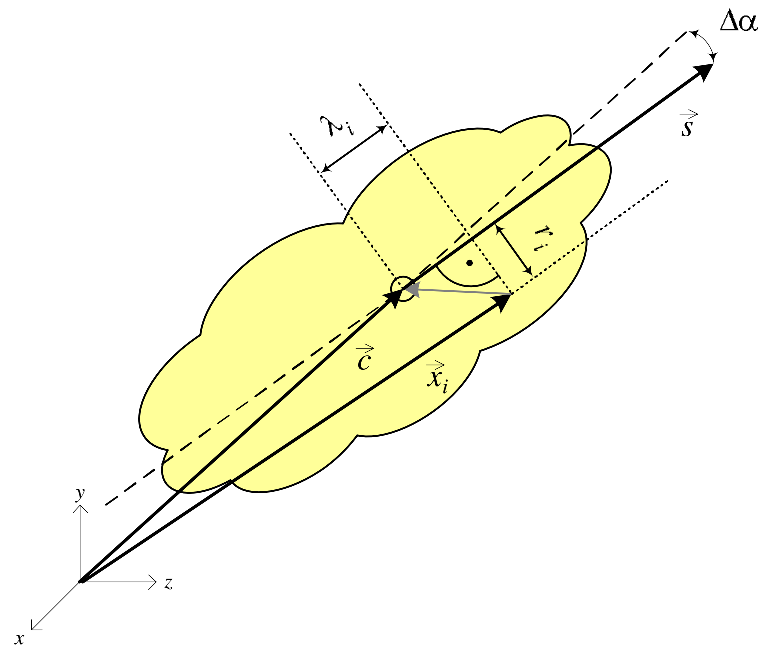

Figure B.1: *Cluster geometry reference. The principal shower axis $\vec{s}$ is typically defined by the spatial cell signal distribution in the cluster. The center-of-gravity of the cluster is pointed to by $\vec{c}$, while the location of a cell is given by $\vec{x}_i$(both originating at the nominal vertex). The projection variables λ_i and r_i are also indicated.*

$\vec{c}$ is the signal center-of-gravity of the cluster, calculated with respect to the nominal interaction point[X]:

$$\vec{c} = \begin{pmatrix} c_x = \left(\sum_{i|E_i>0} E_i x_i \right) / E_{norm} \\ c_y = \left(\sum_{i|E_i>0} E_i y_i \right) / E_{norm} \\ c_z = \left(\sum_{i|E_i>0} E_i z_i \right) / E_{norm} \end{pmatrix} \tag{B.1}$$

Here $\vec{x}_i = (x_i, y_i, z_i)$ denotes the cell location in Euclidian coordinates. The signal normalization E_{norm} is the sum of cluster cell energies E_i, with only cells with $E_i > 0$ contributing:

$$E_{norm} = \sum_{i|E_i>0} E_i \tag{B.2}$$

The principal shower (cluster) axis $\vec{s}$ is determined by the spatial cell correlations, given

[X] this reference is identical to the geometrical system of reference of the `CaloCells` and can change accordingly.

by:

$$\sigma_{xx} = \sum_{i|E_i>0} E_i^2 (x_i - c_x)^2 \Bigg/ \sum_{i|E_i>0} E_i^2$$

$$\sigma_{xy} = \sum_{i|E_i>0} E_i^2 (x_i - c_x)(y_i - c_y) \Bigg/ \sum_{i|E_i>0} E_i^2 ,$$

with σ_{xz}, σ_{yy}, σ_{yz}, and σ_{zz} calculated accordingly. The axis direction is then determined by the eigenvector of the symmetric matrix σ_{ij}'s, with $i, j = x, y, z$, with its direction closest to $\vec{c}$. If the angle $\Delta\alpha = \angle(\vec{s}, \vec{c}) > 30°$, $\vec{s}$ is set to be identical to $\vec{c}$. This is typically the case when all cells in the cluster are in one longitudinal calorimter sampling only.

The cell distance from the shower axis r_i and the cell distance from the cluster center-of-gravity along the shower axis λ_i are the given by (see Figure B.1):

$$r_i = |(\vec{x}_i - \vec{c}) \times \vec{s}\,| \quad \text{and} \quad \lambda_i = (\vec{x}_i - \vec{c}\,) \cdot \vec{s}. \tag{B.3}$$

Note that $r_i \geq 0$ in all cases, while λ_i is a signed quantity, with $\lambda_i < 0$ indicating a cell location along $\vec{s}$ before the center-of-gravity $\vec{c}$. The description of all available cluster moments, using these and other obvious variables, follows below.

`CaloClusterMoment::FIRST_PHI` is the first moment $\langle\varphi\rangle$ in azimuth, defined as

$$\langle\varphi\rangle = \frac{1}{E_{norm}} \cdot \sum_{i|E_i>0} E_i \varphi_i .$$

This moment is the measure of the central cluster azimuth. φ_i is the azimuth of cell i, typically defined by the cell's geometrical center. Wrap-around effects due to $\varphi_i \in [-\pi, +\pi]$ are corrected in the calculation of $\langle\varphi\rangle$.

`CaloClusterMoment::FIRST_ETA` is the first moment $\langle\eta\rangle$ in pseudorapidity, defined as

$$\langle\eta\rangle = \frac{1}{E_{norm}} \cdot \sum_{i|E_i>0} E_i \eta_i$$

This moment is a measure of the central cluster pseudorapidity. The cell pseudorapidities are defined by the central rapidity of each cell in the projective calorimeters (cell represents a regular bin $(\eta_i - \Delta\eta/2,\ \eta_i + \Delta\eta/2)$ in the EMB, EMEC, HEC and Tile calorimeters), or by the geometrical center of the cell in linear coordinates (FCal).

`CaloClusterMoment::SECOND_R` is the second lateral moment $\langle r^2\rangle$. This moment is defined with respect to the shower axis $\vec{s}$ and the shower center $\vec{c}$ as:

$$\left\langle r^2 \right\rangle = \frac{1}{E_{norm}} \cdot \sum_{i|E_i>0} E_i r_i^2 \tag{B.4}$$

r_i is caluclated as shown in eq.(B.3). $\langle r^2\rangle$ is a measure for the energy-weighted cluster width perpendicular to the shower axis $\vec{s}$.

`CaloClusterMoment::SECOND_LAMBDA` is the second longitudinal moment $\langle\lambda^2\rangle$, again defined with respect to the shower axis $\vec{s}$ and the shower (cluster) center $\vec{c}$, as

$$\left\langle\lambda^2\right\rangle = \frac{1}{E_{norm}} \cdot \sum_{i|E_i>0} E_i\lambda_i^2 \tag{B.5}$$

This moment measures the energy-weighted longitudinal (along the shower axis) cluster extension. The calculation of the λ_is is shown in eq.(B.3).

`CaloClusterMoment::DELTA_PHI` is the difference $\Delta\varphi$ in azimuth between the principal shower axis $\vec{s}$ and the direction of the center-of-gravity $\vec{c}$, i.e. $\Delta\varphi = \varphi_s - \varphi_c$. The wrap-around effect of φ is taken into account, $\Delta\varphi \in [-\pi, +\pi]$. If the cluster has less than three cells, $\Delta\varphi = 0$ because the principal cluster axis cannot be measured safely (in this case, $\vec{s} \equiv \vec{c}$ by convention).

`CaloClusterMoment::DELTA_THETA` is the difference $\Delta\theta$ in polar angle between the principal shower axis given by $\vec{s}$ and the direction of the center of gravity $\vec{c}$(see above): $\Delta\theta = \theta_s - \theta_c$. If the cluster has less than three cells, $\Delta\theta = 0$ because $\vec{s} \equiv \vec{c}$ by convention.

`CaloClusterMoment::DELTA_ALPHA` is the angle $\Delta\alpha$ between $\vec{s}$ and $\vec{c}$, $\Delta\alpha = \angle\left(\vec{s}, \vec{c}\right)$, see Figure B.1. $\Delta\alpha = 0$ if the cluster has less than three cells, as $\vec{s} \equiv \vec{c}$ by convention.

`CaloClusterMoment::CENTER_X`

`CaloClusterMoment::CENTER_Y`

`CaloClusterMoment::CENTER_Z` are the (signal) center-of-gravity coordinates for the cluster, as measured by $\vec{c} = (c_x, c_y, c_z)$, with the obvious assignments $c_x \rightarrow$ `CENTER_X` etc.

`CaloClusterMoment::CENTER_LAMBDA` is the distance λ_c from the entry point of the shower axis $\vec{s}$ at the front face of the calorimeter to the cluster center-of-gravity $\vec{c}$, measured along $\vec{s}$ ($\lambda_c > 0$ by convention).

`CaloClusterMoment::LATERAL` is a measure for the normalized lateral (with respect to $\vec{s}$) moment $\mu_\perp$. It is defined as:

$$\mu_\perp = \sum_{i=3}^{N_c} E_i r_i^2 \Bigg/ \left(\rho_0 + \sum_{i=3}^{N_c} E_i r_i^2\right), \text{ with } \rho_0 = \sum_{i=1}^{\min(2,N_c)} E_i \cdot \max\left(r_i, r_{min}\right)^2 \tag{B.6}$$

Here it is assumed that the $i = 1 \ldots N_c$ cells in the cluster are ordered with respect to their energy E_i such that $E_1 > E_2 > E_3 > \cdots > E_{N_c}$, with all $E_i > 0$ (only cells with positive signals are considered here). r_{min} is a parameter of the algorithm, which accounts for some typical lateral cell extension[XI]. The r_i are indicated in Figure B.1 and defined in eq.(B.3). ρ_0 is calculated from the cells with the largest and second largest signal only.

$\mu_\perp$ is normalized in that $0 \leq \mu_\perp < 1$, which can easily be seen by looking at its value as function of the number of cells in the cluster N_c (with $\rho_i = E_i r_i^2 > 0$ for

[XI] represents a rough estimate of the lateral cell location error with respect to the shower axis $\vec{s}$. The present default is $r_{min} = 4$ cm.

$i \geq 3$ and ρ_0 as defined in eq.(B.6)):

$$\mu_\perp = \begin{cases} 0 & N_c = 1,2 \\ 1/(1+\rho_0/\rho_3) & N_c = 3 \\ 1/(1+\rho_0/(\rho_3+\rho_4)) & N_c = 4 \quad \text{etc.} \end{cases} .$$

`CaloClusterMoment::LONGITUDINAL` is a measure for the normalized longitudinal (with respect to $\vec{s}$) moment $\mu_{||}$. It is calculated in a similar fashion as the lateral normalized moment $\mu_\perp$ in eq.(B.6), except that the lateral projection r_i is replaced by the longitudinal projection λ_i, as defined in eq.(B.3) and shown in Figure B.1. The two cells with the largest signals then define ξ_0 similar to ρ_0 as

$$\xi_0 = \sum_{i=1}^{\min(2,N_c)} E_i \max(\lambda_i, \lambda_{min})^2 .$$

Again, cells in the cluster are assumed to be ordered by their signal E_i such that $E_1 > E_{N_c}$. λ_{min} accounts for the typical logitudinal cell depth[XII] and therefore somewhat reflects the uncertainty of the longitudinal cell location projected onto the shower axis $\vec{s}$.

Inspecting $\mu_{||}$ as a function of the number of cells yields

$$\mu_{||} = \begin{cases} 0 & N_c = 1,2 \\ 1/(1+\xi_0/\xi_3) & N_c = 3 \\ 1/(1+\xi_0/(\xi_3+\xi_4)) & N_c = 4 \quad \text{etc.} \end{cases} ,$$

with $\xi_i = E_i\lambda_i^2 > 0$ for $i \geq 3$, thus the normalization $0 \leq \mu_{||} < 1$.

```
void CaloCluster::setMoments(const moments_map& theMoments)
```

Visibility .... public
Interface(s) .... `CaloCluster::setMoments(theMoments)`
Implementation(s) .... `CaloCluster::setMoments(theMoments)`

Variable	*Type*	*Comment*
`theMoments`	`CaloCluster::moments_map&`	reference to a non-modifiable map of moments

Sets the map of moments into the `CaloCluster` object. The map key is the moment type indicator `CaloClusterMoment::MomentType`, while the map data is the associated `CaloClusterMoment`.

```
bool CaloCluster::is_valid_sampling(CaloSampling::CaloSample& sample)
```

[*from original implementation in* `LArCluster::is_valid_sampling(sample)`]

[XII] the default value is $\lambda_{min} = 10$ cm.