EMC covariance matrix

Inside pandaroot the class emc/EmcReco/PndEmcErrorMatrix.cxx is responsible for EMC covariance matrix calculation.

Covariance matrix for neutral candidates is estimated in the following way:

- For single photon events errors are estimated as standard deviations of residual distribution between energy-position of reconstructed cluster and MC Truth energy-positions of generated photons.
- Errors are calculated in dependence on the energy for two separate cases:
  1. Endcaps: errors are calculated for coordinates ($\sigma(E)$, $\sigma(x)$, $\sigma(y)$) at fixed z=100 cm and energy dependence is parameterized with the following functions:
  $$\frac{\sigma(E)}{E} = \frac{a^2}{E^n} + c^2 + \frac{q^2}{E^2} \tag{1}$$
  $$\sigma(x) = \frac{a^2}{E^n} + c^2 \tag{2}$$
  $$\sigma(y) = \frac{a^2}{E^n} + c^2 \tag{3}$$
  2. Barrel: errors are calculated for coordinates ($\sigma(E)$, $\sigma(\phi)$, $\sigma(z)$) at fixed R=100 cm with parametrization of energy dependence:
  $$\frac{\sigma(E)}{E} = \frac{a^2}{E^n} + c^2 + \frac{q^2}{E^2} \tag{4}$$
  $$\sigma(z) = \frac{a^2}{E^n} + c^2 \tag{5}$$
  $$\sigma(\phi) = \frac{a^2}{E^n} + c^2 \tag{6}$$
- In emc/EmcReco/PndEmcErrorMatrix.cxx class inside the method

  ```
  TMatrixD PndEmcErrorMatrix::GetErrorMatrix(const PndEmcCluster &cluster) ()
  ```

error matrix for both cases are reduced to (E, θ, ϕ, R) represenation.

- The method

  `TMatrixD PndEmcErrorMatrix::Get4MomentumErrorMatrix(const PndEmcCluster &cluster)`

  transforms error matrix to (p_x, p_y, p_z, E) representation by

$$Cov(p_x, p_y, p_z, E) = M * Cov(E, \theta, \phi, R) * M^T \tag{7}$$

  with

$$M = \begin{pmatrix} \frac{\partial p_x}{\partial E} & \frac{\partial p_x}{\partial \theta} & \frac{\partial p_x}{\partial \phi} & \frac{\partial p_x}{\partial R} \\ \frac{\partial p_y}{\partial E} & \frac{\partial p_y}{\partial \theta} & \frac{\partial p_y}{\partial \phi} & \frac{\partial p_y}{\partial R} \\ \frac{\partial p_z}{\partial E} & \frac{\partial p_z}{\partial \theta} & \frac{\partial p_z}{\partial \phi} & \frac{\partial p_z}{\partial R} \\ \frac{\partial E}{\partial E} & \frac{\partial E}{\partial \theta} & \frac{\partial E}{\partial \phi} & \frac{\partial E}{\partial R} \end{pmatrix} = \begin{pmatrix} \sin(\theta)\cos(\phi) & E\cos(\theta)\cos(\phi) & -E\sin(\theta)\sin(\phi) & 0 \\ \sin(\theta)\sin(\phi) & E\cos(\theta)\sin(\phi) & E\sin(\theta)\cos(\phi) & 0 \\ \cos(\theta) & -E\sin(\theta) & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix} \tag{8}$$

  taking into account

$$p_x = E\sin(\theta)\cos(\phi) \tag{9}$$

$$p_y = E\sin(\theta)\sin(\phi) \tag{10}$$

$$p_z = E\cos(\theta) \tag{11}$$

  The operation of matrix multiplication is implemented in the following method

  `TMatrixD similarityWith(const TMatrixD& mat, const TMatrixD& m1)`

- To obtain 7x7 error matrix in (x,y,z,p_x,p_y,p_z,E) representation the method

  `TMatrixD GetErrorP7(const PndEmcCluster &cluster) const;`

  has been implemented, which converts error matrix from (E, θ, ϕ, R) representation with matrix multiplication

$$Cov(x, y, z, p_x, p_y, p_z, E) = M * Cov(E, \theta, \phi, R) * M^T \tag{12}$$

$$M = \begin{pmatrix} \frac{\partial x}{\partial E} & \frac{\partial x}{\partial \theta} & \frac{\partial x}{\partial \phi} & \frac{\partial x}{\partial R} \\ \frac{\partial y}{\partial E} & \frac{\partial y}{\partial \theta} & \frac{\partial y}{\partial \phi} & \frac{\partial y}{\partial R} \\ \frac{\partial z}{\partial E} & \frac{\partial z}{\partial \theta} & \frac{\partial z}{\partial \phi} & \frac{\partial z}{\partial R} \\ \frac{\partial p_x}{\partial E} & \frac{\partial p_x}{\partial \theta} & \frac{\partial p_x}{\partial \phi} & \frac{\partial p_x}{\partial R} \\ \frac{\partial p_y}{\partial E} & \frac{\partial p_y}{\partial \theta} & \frac{\partial p_y}{\partial \phi} & \frac{\partial p_y}{\partial R} \\ \frac{\partial p_z}{\partial E} & \frac{\partial p_z}{\partial \theta} & \frac{\partial p_z}{\partial \phi} & \frac{\partial p_z}{\partial R} \\ \frac{\partial E}{\partial E} & \frac{\partial E}{\partial \theta} & \frac{\partial E}{\partial \phi} & \frac{\partial E}{\partial R} \end{pmatrix} = \begin{pmatrix} 0 & R\cos(\theta)\cos(\phi) & -R\sin(\theta)\sin(\phi) & \sin(\theta)\cos(\phi) \\ 0 & R\cos(\theta)\sin(\phi) & R\sin(\theta)\cos(\phi) & \sin(\theta)\sin(\phi) \\ 0 & -R\sin(\theta) & 0 & \cos(\theta) \\ \sin(\theta)\cos(\phi) & E\cos(\theta)\cos(\phi) & -E\sin(\theta)\sin(\phi) & 0 \\ \sin(\theta)\sin(\phi) & E\cos(\theta)\sin(\phi) & E\sin(\theta)\cos(\phi) & 0 \\ \cos(\theta) & -E\sin(\theta) & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix} \tag{13}$$