# ELECTROMAGNETIC CALORIMETER CALIBRATION WITH $\pi^0$

*65th Scottish Universities Summer School in Physics: LHC Physics*

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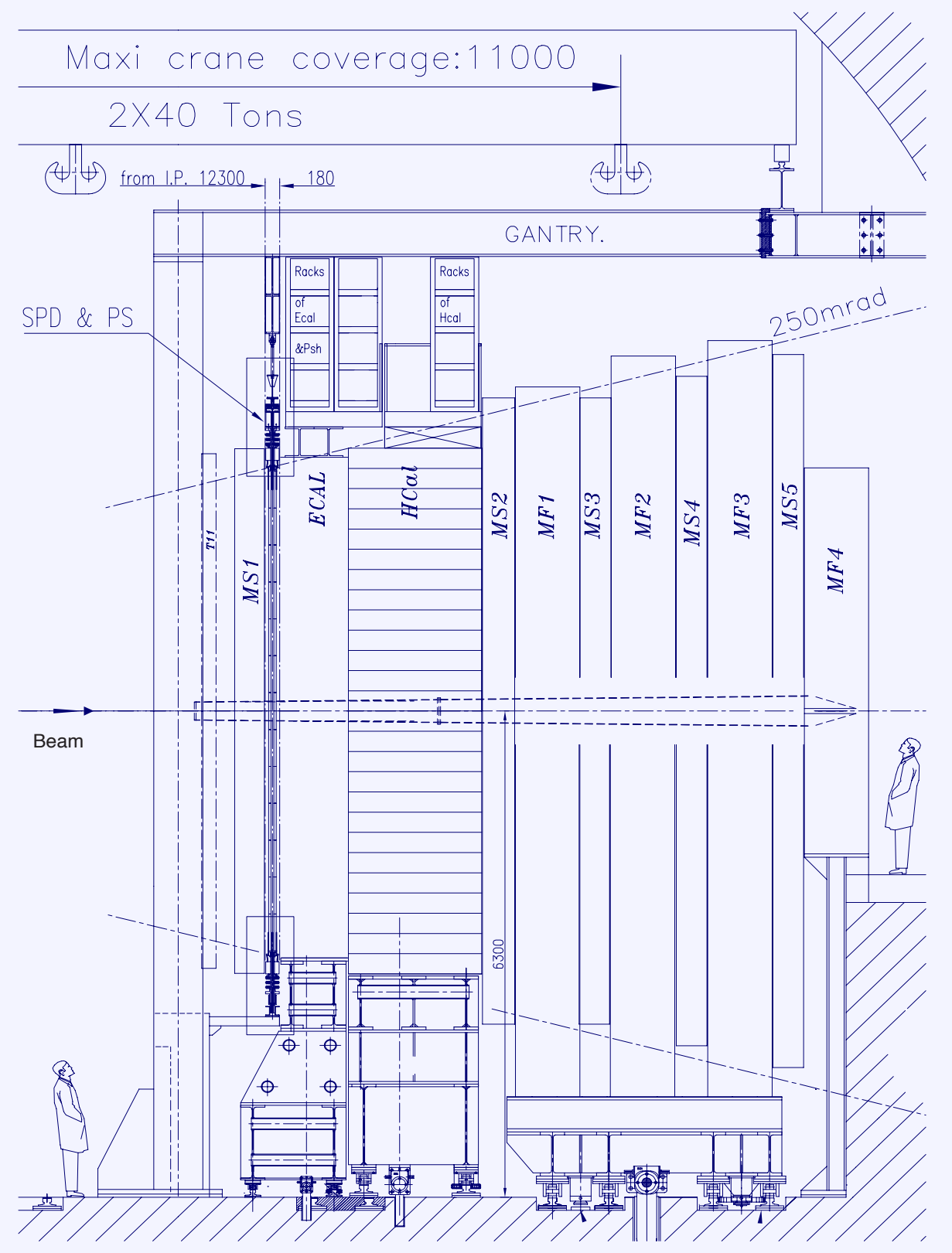
## THE LHCb CALORIMETRY SYSTEM

### OVERVIEW

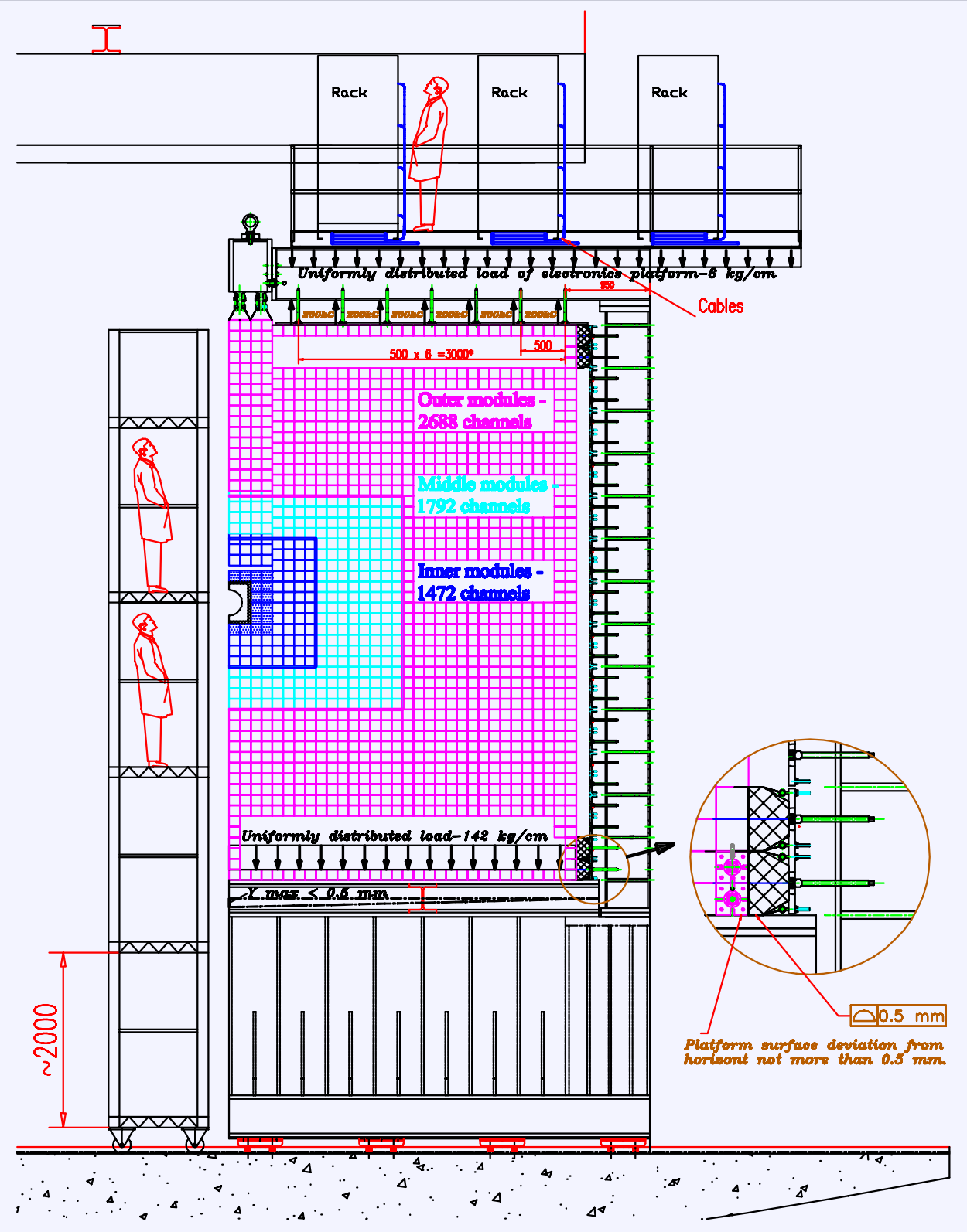


The main purpose of the LHCb calorimeter system is the identification of hadrons, electrons and photons, and the measurement of their energies and positions. This information is used in the first level of trigger of LHCb, as well as in offline event analysis. Additionally, it allows the reconstruction of *B*-decay channels containing a prompt photon or $\pi^0$.

The LHCb calorimeter consists in 4 elements, all of which employ scintillators coupled to wavelength-shifting fibres read out by fast photodetectors:

- Single layer scintillator pad (**SPD**): differentiation between charged and neutral particles.
- Single layer preshower (**PS**): electron/hadron separation and energy correction for electromagnetic showers that begin before the calorimeter.
- Electromagnetic calorimeter (**ECAL**): electron identification, photon and electron energy measurements and $\pi^0$ reconstruction.
- Scintillating tile hadron calorimeter (**HCAL**), whose main purpose is to provide data for the L0 hadron trigger.

### THE ELECTROMAGNETIC CALORIMETER (ECAL)



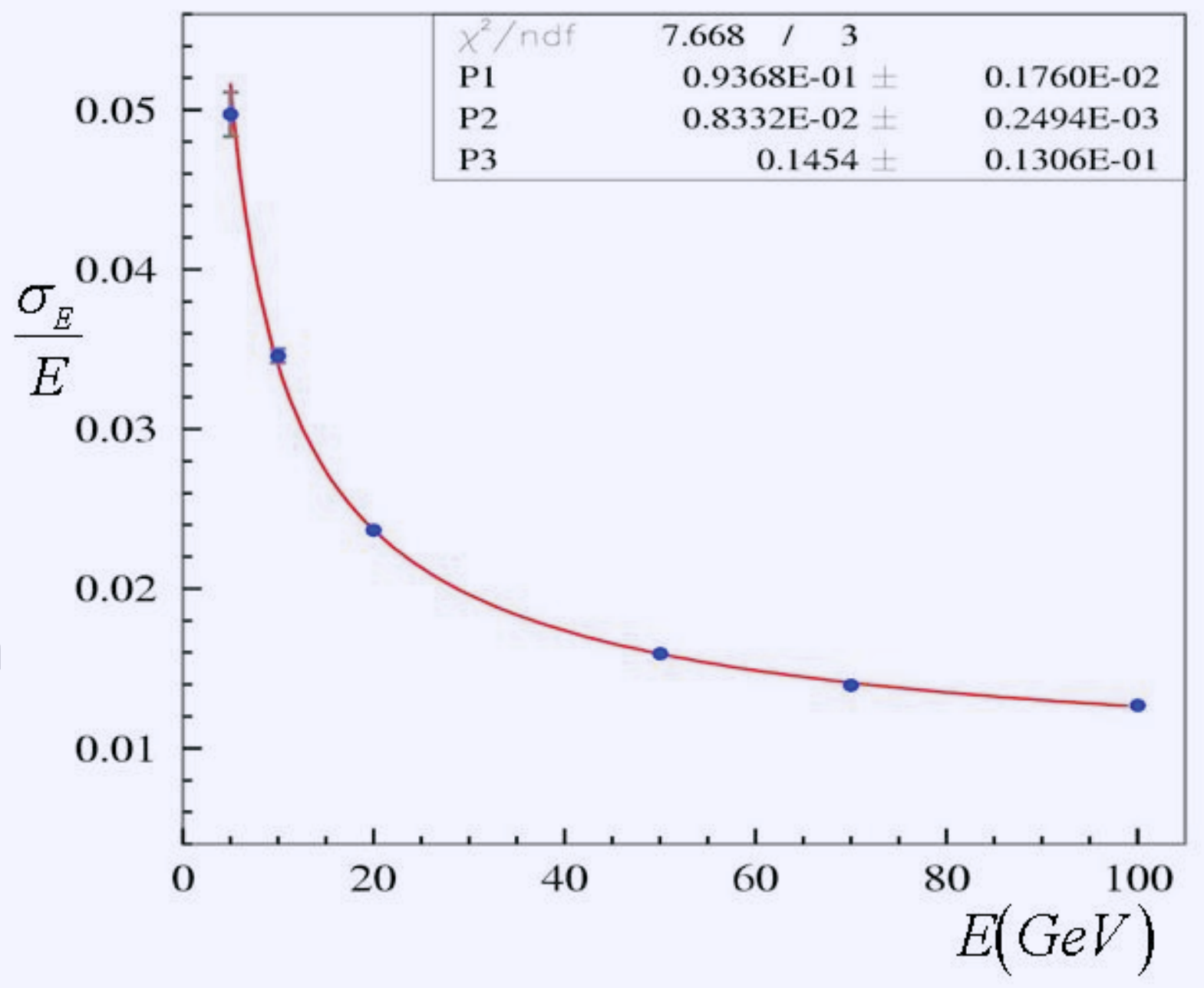
The ECAL has non-uniform granularity, and one can distinguish 3 different areas with different cell sizes: inner, middle and outer. It corresponds with that of the PS and SPD. It is a "Shashlik"-type calorimeter, built with individual modules made of lead absorber plates interspaced with scintillator tiles as active material. There are a total of 66 lead/scintillator layers, resulting in a total depth of 25 radiation lengths.

The expected energy resolution is:

$$\frac{\sigma(E)}{E} = \frac{10\%}{\sqrt{E}} \oplus 1.5\% \text{ } (E \text{ in GeV})$$

The measured energy resolution with test-beam data gives:

$$\frac{\sigma(E)}{E} = \frac{(9.4 \pm 0.2)\%}{\sqrt{E}} \oplus (0.83 \pm 0.02)\%$$



## REFERENCES

[1] *LHCb Calorimeters, Technical Design Report* (2000), CERN-LHCC-2000-036.
[2] *The road map for the radiative decays of beauty hadrons at LHCb* (2009), LHCB-ROADMAP4-001.
[3] *On the possibility of in situ calibration of LHCb calorimeters* (2000), CERN-LHCb-2000-051
[4] *Online $\pi^0$ calibration of ECAL* (2000), HERA-B/00-103.

## CALIBRATING THE LHCb ELECTROMAGNETIC CALORIMETER

### CELL EQUALIZATION

- Initial tests before module assembly showed an initial light yield equalized within 4.3-8.0%.
- Phototube gains are remeasured *in situ* with the **LED system**.
- **Energy flow** method effectively results in the calibration of modules at the level of 3.7-5% for an initial miscalibration of 20%.

### FINE CALIBRATION

- Calibration using **minimum ionizing particles**. Only valid for outer ECAL.
- Calibration of ECAL with **$\pi^0$**. Valid only for low-$E_T$ range ( < 1.5 GeV)
- Simultaneous calibration of ECAL and PS using **electrons** with $E_T$ > 1 GeV.

### CALIBRATION WITH $\pi^0$

#### ITERATIVE METHOD

Successfully used by the HERA-B Collaboration as the main calibration technique, this method provides a robust and precise ECAL calibration and is tracking independent. It is based on the relation between the energy shift of the photon and the shift of the $\pi^0$ mass peak,

$$m^2_{\gamma\gamma} = 2E^\gamma_1 E^\gamma_2 (1 - \cos\theta_{\gamma\gamma})$$

The reconstructed energy of the photon can be written as

$$E^{\rm rec}_\gamma = E_{PS} f_1(x_b, y_b) + (E_{\rm seed} + \sum_{i \neq \rm seed} E'_i) f_2(x_b, y_b)$$

where $f_1$ and $f_2$ are some functions, $E_{PS}$ is the energy deposited in the PS and $x_b$ and $y_b$ are the x- and y- coordinates of the weighted barycenter cluster. $f_2$ takes into account the transversal non-uniformity of the response, and in particular the transversal energy leakage. It is, however, close to unity: $f_2 = 1+O(2\%)$.

Due to the coarse structure of ECAL, $E^{\rm rec}$ is close to $E^{\rm seed}$, and for photons with $E_{PS}$=0 they are roughly proportional.

With that in mind, the actual procedure can work as follows:

1. For each event, reconstructed photons with no energy deposition in the PS are selected and combined to calculate the invariant mass. If the initial miscalibration of ECAL does not exceed 15%, one should see the peak in the vicinity of the nominal mass of the $\pi^0$ meson.
2. A Gaussian distribution is fitted for the peak, with a polynomial describing the background. A correction coefficient is calculated for each cell with the formula:

$$\lambda' = \frac{E^{\rm true}_\gamma}{E^{\rm rec}_\gamma} = 1 - \frac{\delta m_{\gamma\gamma}}{m_{\gamma\gamma}}$$

This formula takes into account the fact that all the miscalibration is assumed to be in the seed cell, and corrects overcalibration issues.

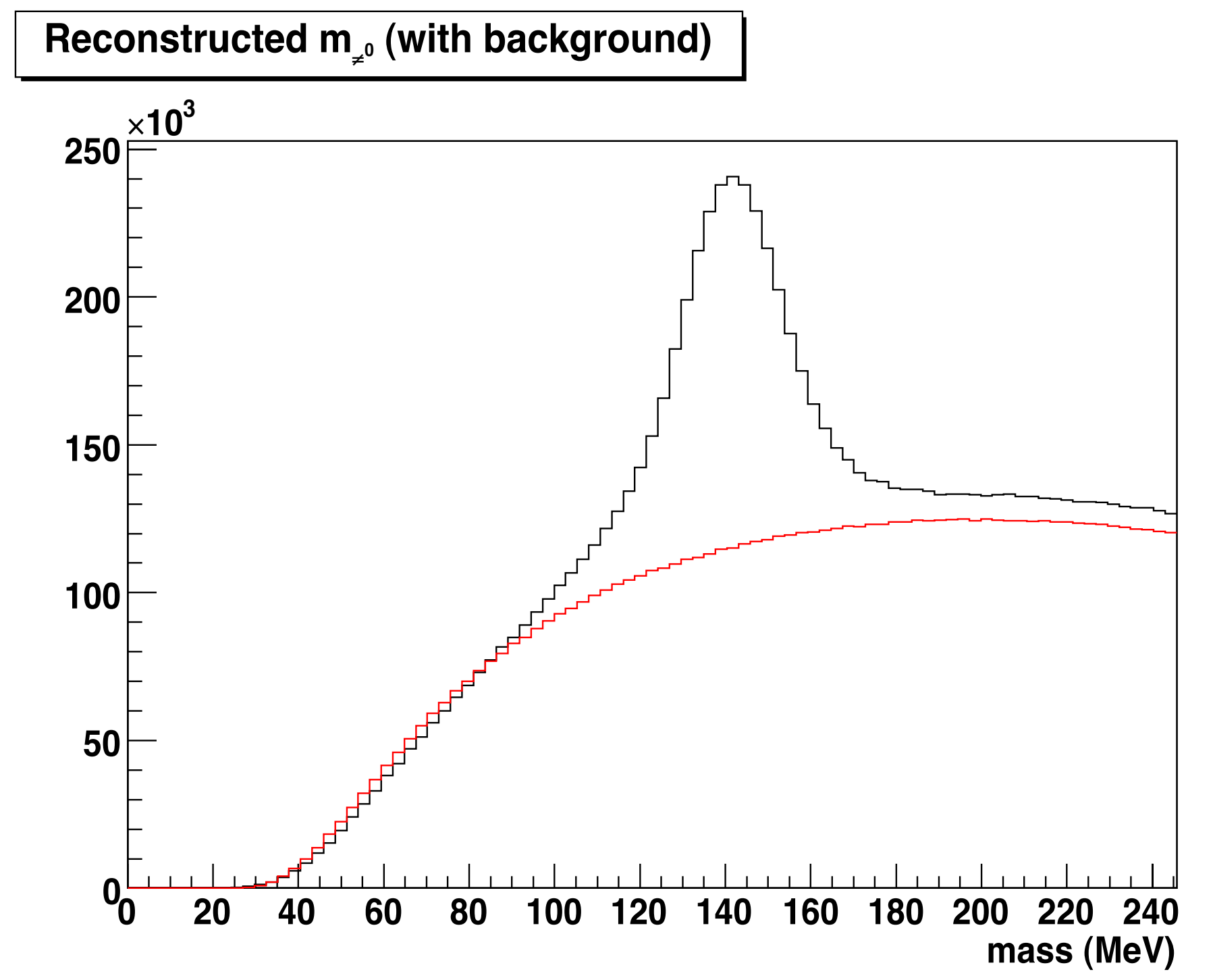
3. This "primary" iteration (steps 1-2) is repeated until it stabilizes.
4. Reconstruction of photons taking into account the new calibration constants is performed, and a "primary" iteration is carried out again. This "secondary" iteration is repeated until convergence is achieved.

#### BACKGROUND GENERATION FROM DATA

The main source of background for the $\pi^0$ mass peak is combinatorics. Since the shape of the combinatorial background is highly position-dependent, it is very difficult to estimate its shape using a polynomial function. However, a way to describe combinatorial background directly from the data has been proposed and successfully applied. The procedure is very simple:

1. For each photon, combine it with the other ones and apply proper cuts to obtain the signal.
2. Then, replace the position of all other photons with its symmetric with respect to the beam pipe, i.e. replacing (x,y) by (-x,-y).
3. Combine the given photon with all the "inverted" photons, applying the same cuts, to generate the background.

Once the double counting has been taken into account, it is very easy to eliminate the background from our signal by subtracting the invariant mass histograms.



#### MINIMIZATION METHOD

Taking into account the fact that combinatorial background can be generated with very good precision, one can try to improve the convergence and speed og previous methods. Instead of working on invariant mass distributions, the mass information of all candidates is used. For a given set of signal + background, the correction constants for the seed cells are calculated by maximizing the following function of the calibration constants c:

$$f = \sum_{data} w_i \delta m_i (c_{{\rm seeds},i}) - \frac{1}{2} \sum_{bkg} w_j \delta m_j (c_{{\rm seeds},j})$$

with weight $w_k$ given by a Gaussian distribution with $\mu = m_{\pi^0}$. After the first minimization, it may become necessary to perform some "secondary" iterations in order to achieve full convergence.

First tests of this method have shown very promising results, e.g.. for a miscalibrated sample with constants randomly distributed with a Gaussian of mean 1.0 and sigma 10%, one is able to recover the original calibration.