BELLE electromagnetic calorimeter calibration.

BELLE collaboration
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- **Electronics calibration**
- **Cosmic calibration**
- **Absolute calibration using Bhabha and** $e^+e^- \to \gamma\gamma$
- **Nonlinearity estimation using** $\pi^0 \to \gamma\gamma$

TDC counts to energy deposition.

$$E_i = c_i(TDC_i^{(r)} - Ped_i^{(r)})T_i^{(r)}/T_i^0 = c_i A_i$$

$TDC_i^{(r)}$ - **TDC counts in range (r);**

$Ped_i^{(r)}$ - **pedestal for range (r);**

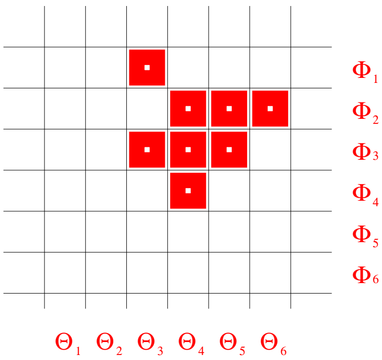
$T_i^{(r)}$ - **test pulse slope for range (r);**

T_i^0 - **reference test pulse slope;**

c_i - **energy calibration constants;**

Photon energy reconstruction

- **Cluster reconstruction.**



$$E_{cl} = \sum E_i$$

$$(\theta_g, \phi_g) = \frac{\sum E_i(\Theta_i, \Phi_i)}{E_{cl}}$$

- **Reconstruction of the most probable photon energy.**

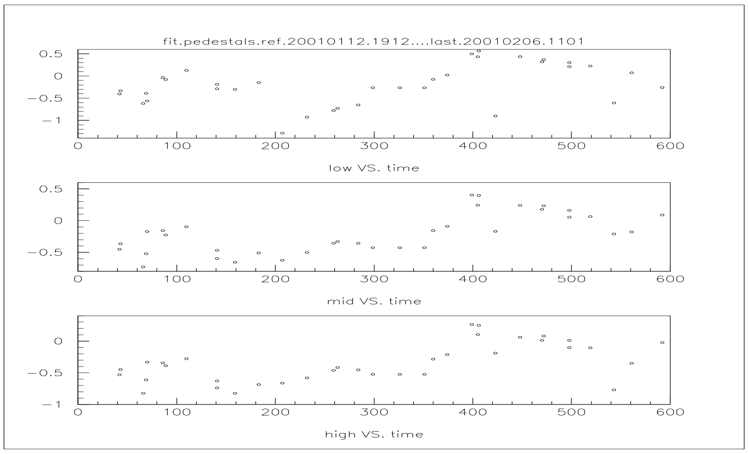
$$E_\gamma = E_{cl} F_{MC}(E_{cl}, \theta_g) C_{non}(E_{cl}, \theta_g)$$

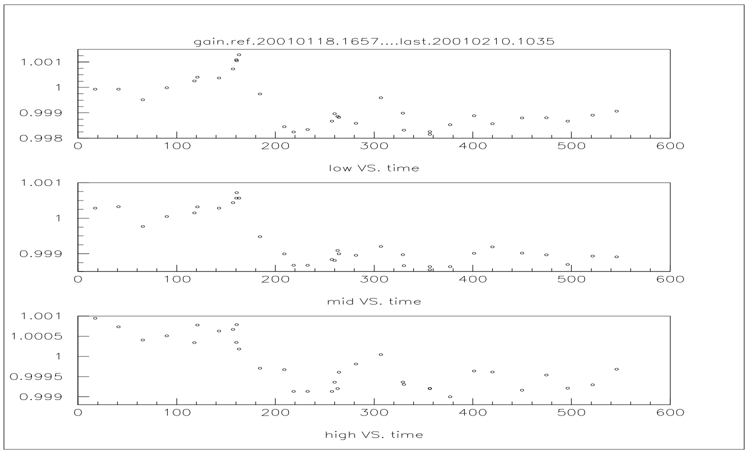
$F_{MC}(E_{cl}, \theta_g)$ - **correction function from MC;**

$C_{non}(E_{cl}, \theta_g)$ - **correction function from experiment.**

Electronics calibration (Every day $\sim 6min$)

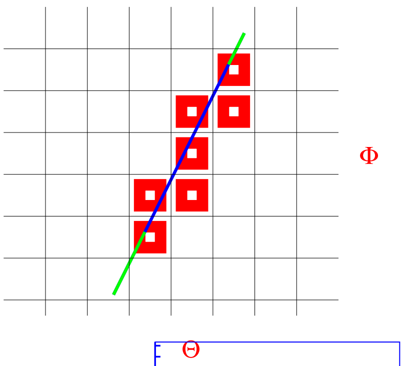
- **Pedestals**
- **Electronics gain**
- **LED**



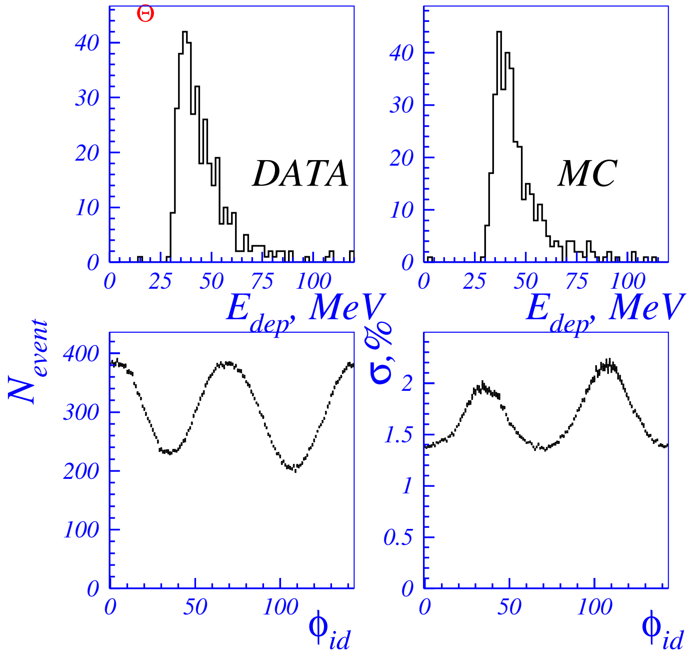


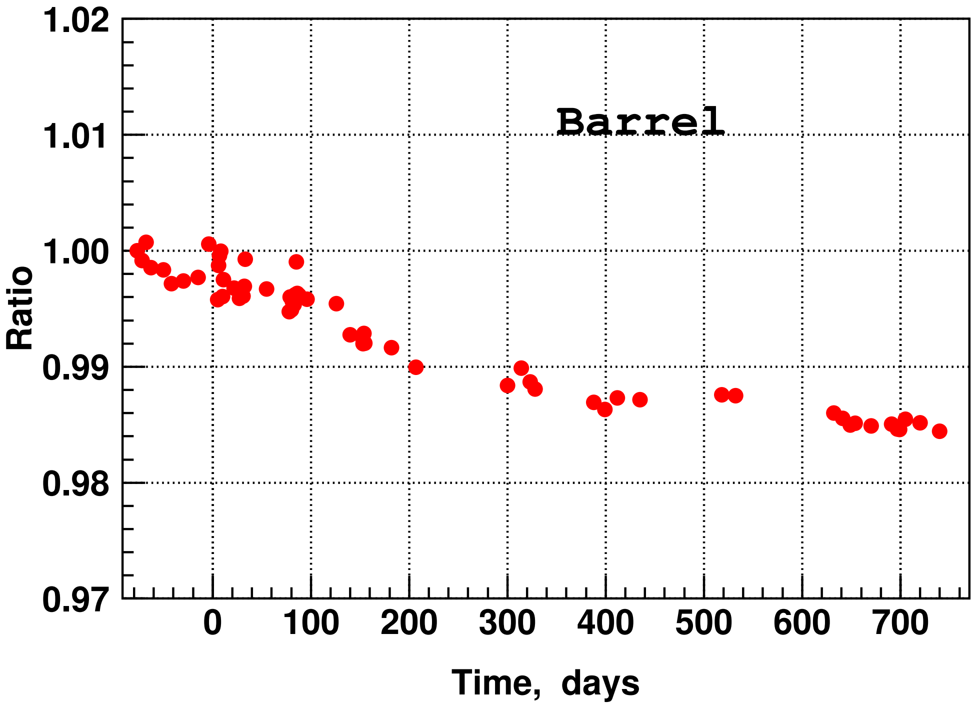
Compensate electronics drift, jumps of signal in case of changing electronic modules.

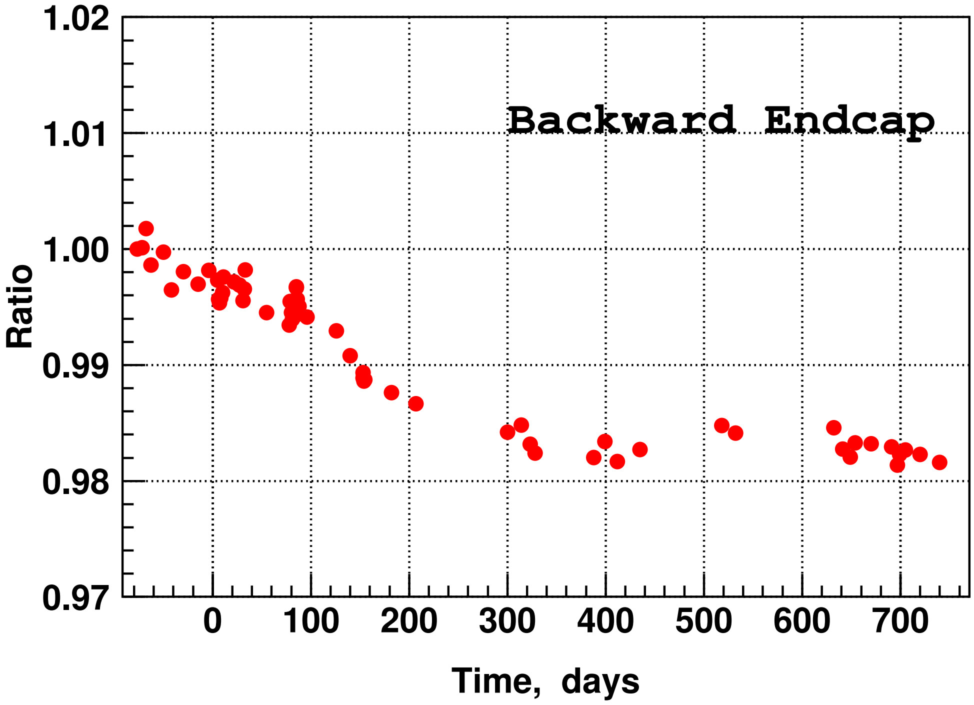
Cosmic calibration(No beam~2 hours)



$E_{up} > 10$ **MeV .and.**
$E_{down} > 10$ **MeV**
Total rate $\sim$ **700 Hz**
Accuracy $1.5 \sim 2\%$




Barrel
Ratio
Time, days
1.02
1.01
1.00
0.99
0.98
0.97
0
100
200
300
400
500
600
700


Backward Endcap
Ratio
Time, days
1.02
1.01
1.00
0.99
0.98
0.97
0
100
200
300
400
500
600
700

Absolute calibration using Bhabha and $e^+e^- \to \gamma\gamma$(1–2 times for experiment)

$$\sum \frac{(\sum c_i^b A_i - E_{calc}(\theta,\phi) f(\theta))^2}{\sigma^2(\theta)} \to min$$

$E_{calc}(\theta,\phi)$ - **Energy from kinematic**

$f(\theta)$ - - **Shower leakage correction obtained from MC**

Bhabha selection criteria

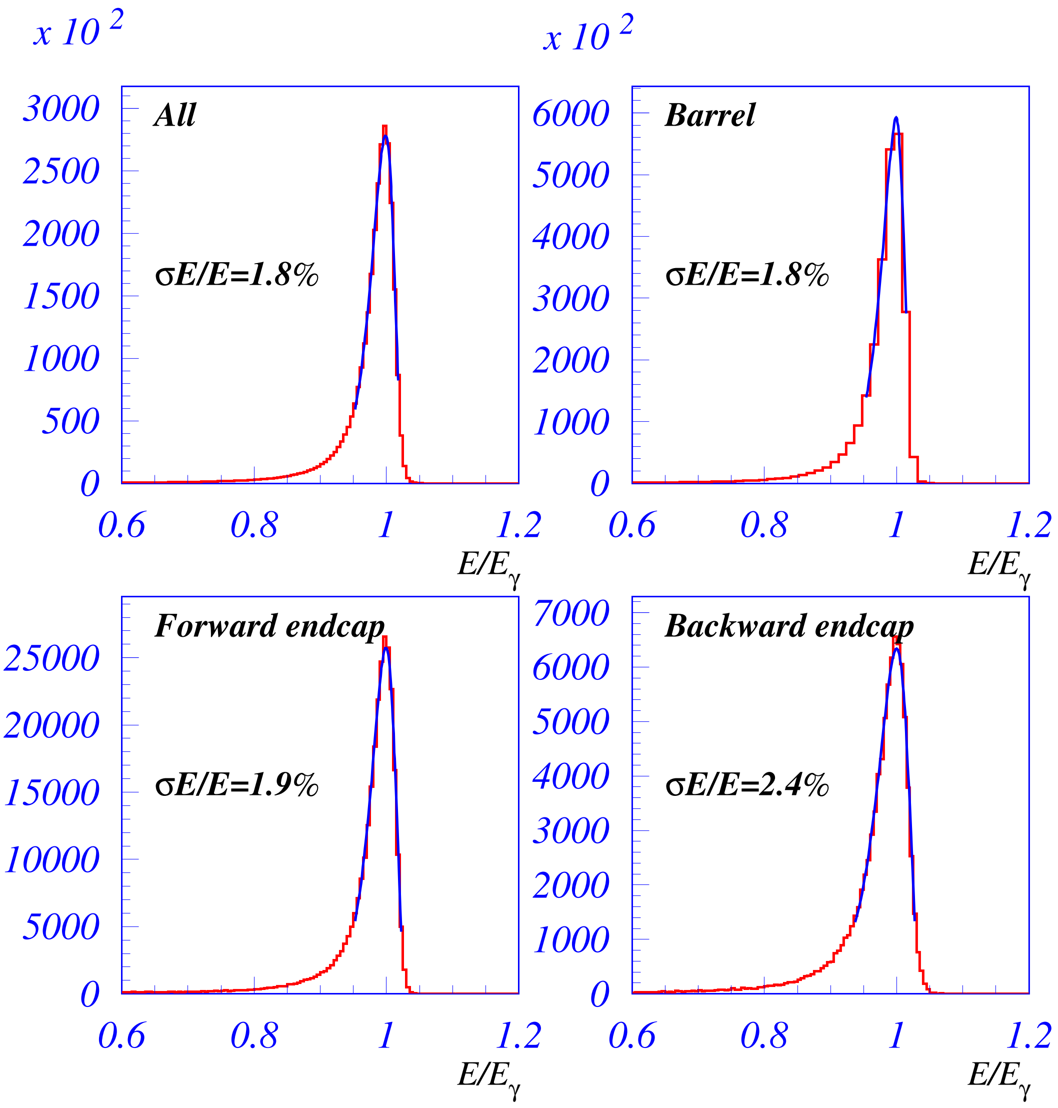
- $\#of track \geq 2$
- $\#of clusters \geq 2$
- $P_{track}^{cms} \geq \sqrt{s}/4$
- $14GeV > E_{tot} > 5GeV$
- $E_{1,2} > 1GeV$
- $E_3 < 0.1GeV$
- $\Delta\psi^{cms} < 1.5°$
- $|E_{e^\pm}/E(\theta,\phi) - 1| < 0.2$

Skim file is prepared during DST production.

Separate program to calculate matrix elements and solve equation of minimization.

For current prescaling factor for Bhabha events(50) the data sample of $2\ fbn^{-1}$ provides the accuracy of $\sim 0.5\%$.

The procedure allows to calibrate 8448 of 8736 counters. For two extremely forward and for three extremely backward layers of crystals there is too thick passive material layer in front of the calorimeter. So the results of cosmic calibration are used for these crystals.


x 10 2
All
σE/E=1.8%
3000
2500
2000
1500
1000
500
0
0.6
0.8
1
1.2
E/Eγ
x 10 2
Barrel
σE/E=1.8%
6000
5000
4000
3000
2000
1000
0
0.6
0.8
1
1.2
E/Eγ
Forward endcap
σE/E=1.9%
25000
20000
15000
10000
5000
0
0.6
0.8
1
1.2
E/Eγ
Backward endcap
σE/E=2.4%
7000
6000
5000
4000
3000
2000
1000
0
0.6
0.8
1
1.2
E/Eγ

$e^+e^- \to \gamma\gamma$ calibration

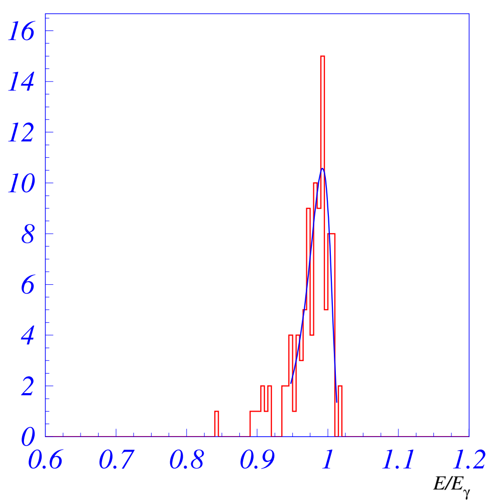
To exclude the MC inaccuracy in e and photon interaction.

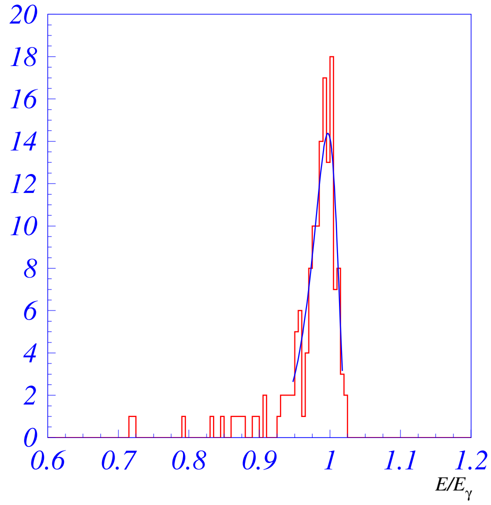
$e^+e^- \to \gamma\gamma$ **selection criteria**

- $\#ofclusters \geq 2$
- $14GeV > E_{tot} > 5GeV$
- $E_3 < 0.1GeV$
- $\Delta\phi^{cms} < 0.02rad$
- $\Delta\theta^{cms} < 0.03rad$
- $|E_\gamma/E(\theta,\phi) - 1| < 0.2$
- **For each crystal ($\Delta\theta, \Delta\phi$ region) histogram is filled.**

Each histogram is fitted by normal logarithmic distribution.

$$dW = \exp\left(-\frac{\ln^2(1-\eta(E-E_p)/\sigma)}{2\sigma_0^2} - \frac{\sigma_0^2}{2}\right)\frac{\eta dE}{\sqrt{2\pi}\sigma\sigma_0}$$

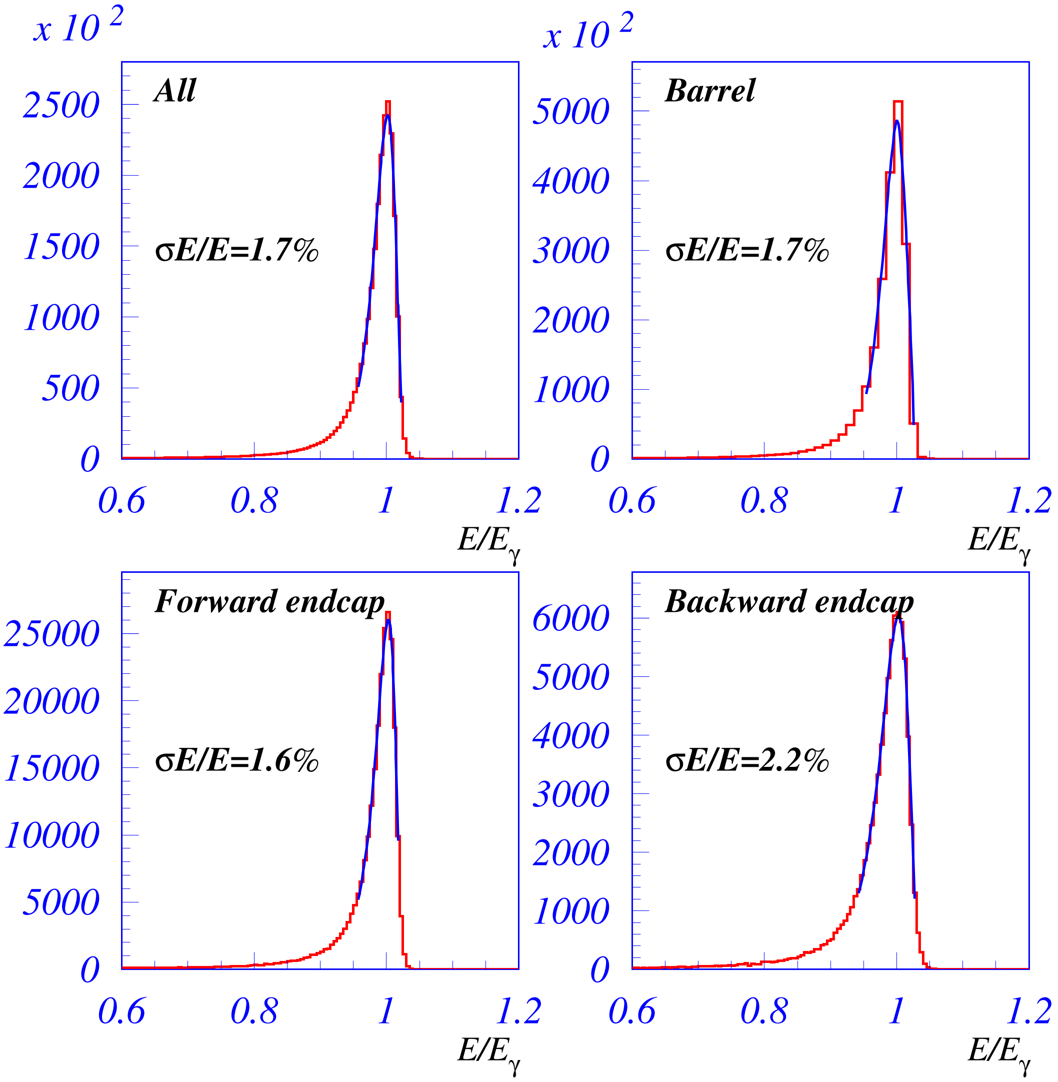




On data sample of full experiment the peak position values (a_i^γ) were obtained.

Final calibration constants are: $c_i = c_i^b/a_i^\gamma$.

After each Bhabha calibration $\gamma\gamma$ calibration is also performed to crosscheck.


x 10 2
All
σE/E=1.7%
2500
2000
1500
1000
500
0
0.6
0.8
1
1.2
E/Eγ
x 10 2
Barrel
σE/E=1.7%
5000
4000
3000
2000
1000
0
0.6
0.8
1
1.2
E/Eγ
Forward endcap
σE/E=1.6%
25000
20000
15000
10000
5000
0
0.6
0.8
1
1.2
E/Eγ
Backward endcap
σE/E=2.2%
6000
5000
4000
3000
2000
1000
0
0.6
0.8
1
1.2
E/Eγ

Nonlinearity estimation using $\pi^0 \to \gamma\gamma$ and $e^+e^- \to e^+e^-\gamma$

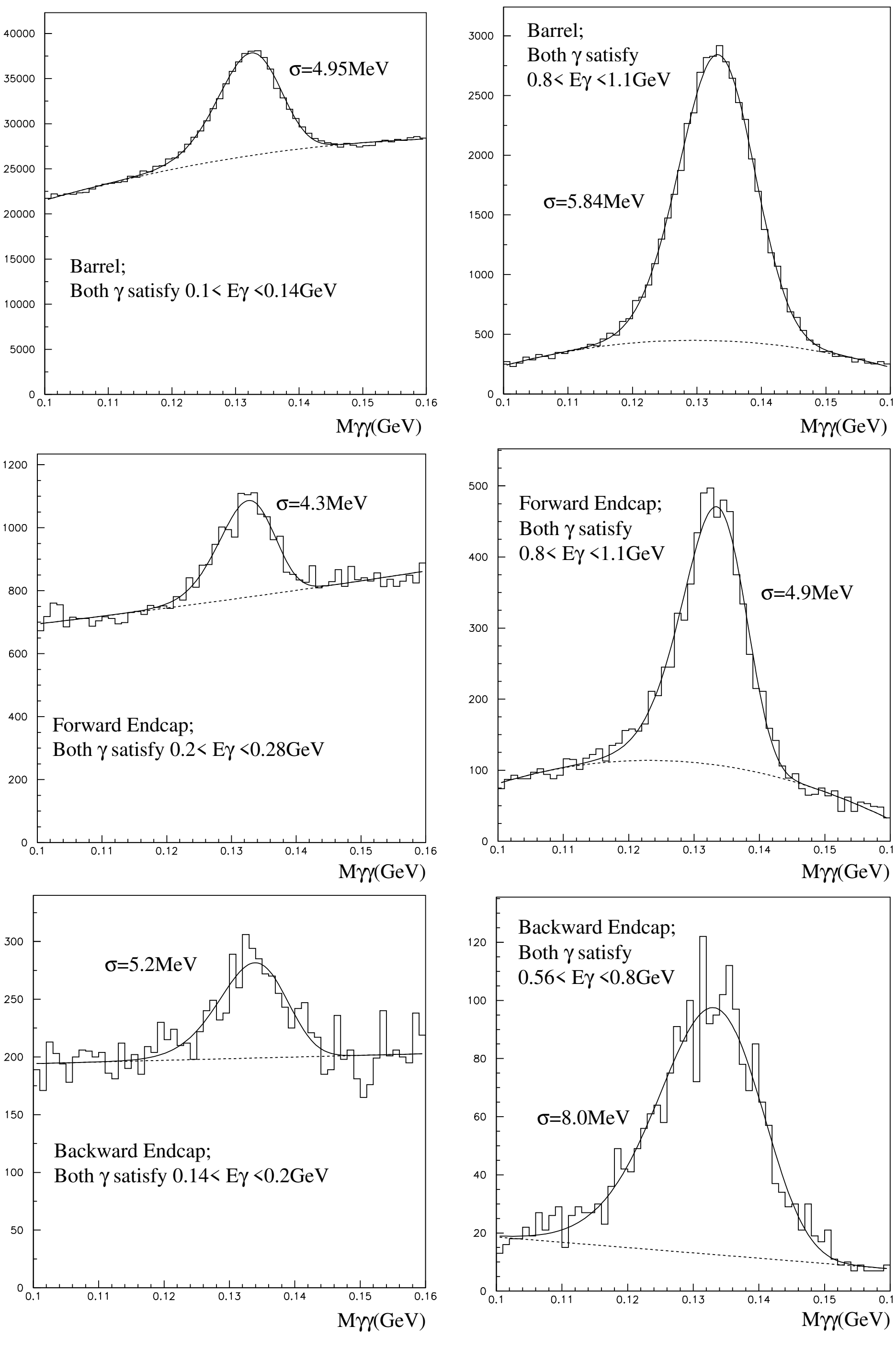
$$m^2_{\gamma\gamma} = 2E_{\gamma 1}E_{\gamma 2}(1-cos\psi) = 2C(E_{\gamma 1})C(E_{\gamma 2})E^0_{\gamma 1}E^0_{\gamma 2}(1-cos\psi)$$

Gamma energy range(from 40 MeV up to 1.3 GeV) was subdivided on 11 regions.

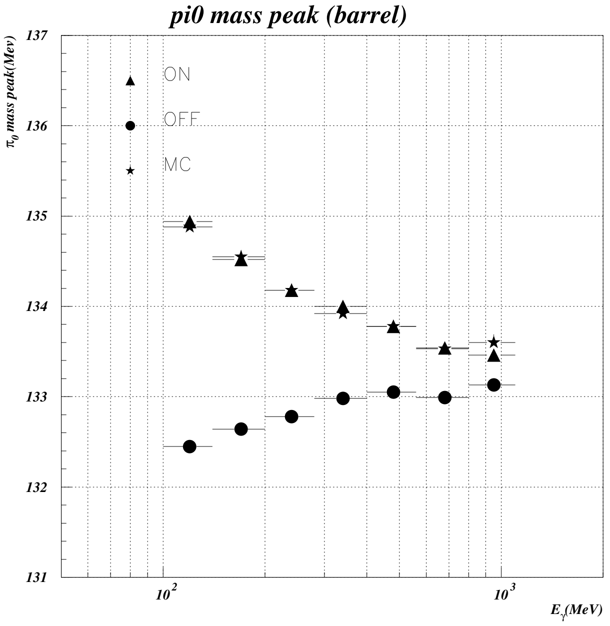
π^0 **peak position are determined for each combination.**

The same procedure was applied for MC. Peak is shifted due to asymmetry of γ **deposited energy distribution.**

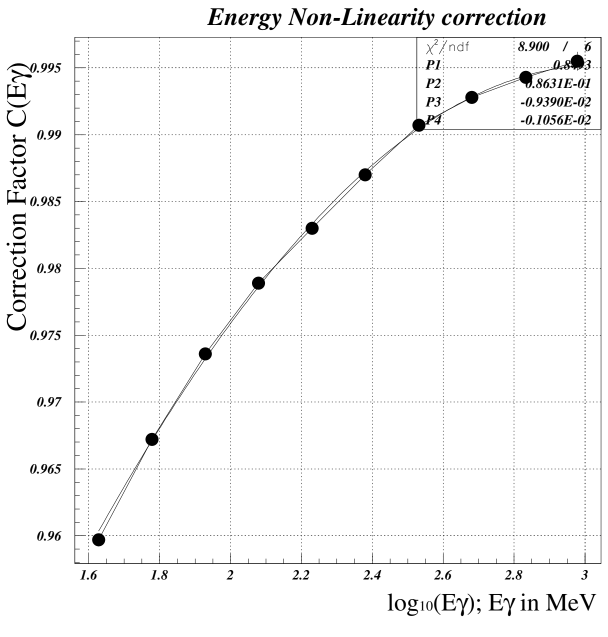
$C(E)$ **are obtained as ratio of experimental and MC peak positions.**



σ=4.95MeV
Barrel;
Both γ satisfy 0.1< Eγ <0.14GeV
Mγγ(GeV)
Barrel;
Both γ satisfy
0.8< Eγ <1.1GeV
σ=5.84MeV
Mγγ(GeV)
σ=4.3MeV
Forward Endcap;
Both γ satisfy 0.2< Eγ <0.28GeV
Mγγ(GeV)
Forward Endcap;
Both γ satisfy
0.8< Eγ <1.1GeV
σ=4.9MeV
Mγγ(GeV)
σ=5.2MeV
Backward Endcap;
Both γ satisfy 0.14< Eγ <0.2GeV
Mγγ(GeV)
Backward Endcap;
Both γ satisfy
0.56< Eγ <0.8GeV
σ=8.0MeV
Mγγ(GeV)



pi0 mass peak (barrel)
π_0 mass peak(Mev)
ON
OFF
MC
E_γ(MeV)



Energy Non-Linearity correction
Correction Factor C(Eγ)
χ^2/ndf 8.900 / 6
P1
P2 0.8631E-01
P3 -0.9390E-02
P4 -0.1056E-02
log10(Eγ); Eγ in MeV

Conclusion

- **The calibration procedure provides the coefficient reconstruction accuracy better than** 0.5%
- **The obtained energy resolution for high energy photons is consistent with MC expectation (about 1.7** $\%$**).**
- **The nonlinearity of the calorimeter is measured using** $\pi^0 \to \gamma\gamma$ **calibration. The nonlinearity is better then** 2% **for photons with energy more then 100 MeV.**