Application of parametric EM shower

- **γ/ π^0 discrimination in ECAL Barrel for unconverted case**
- **Dead channel correction in ECAL Test Beam**

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Outline

- Introduction of parametric EM shower study
- Validation of the EM shower parameterization formulae in CMS ECAL
- γ / π^0 discrimination with the parametric EM shower method
- Results of dead channel correction in ECAL Test Beam
- Summary

Empirical formula to parameterize the EM shower shape

- The longitudinal formula and lateral formula are combined to get the empirical 3-dimentional formula to discribe the EM shower .

- The longitudinal profile of EM shower can be described typically by a Gamma-distribution:

$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

where *t* is the shower depth. *E0* is the total Energy of the shower. *a* and *b* are parameters, which are related to the material and the incident energy. And the relation between a, b and t_{max} (the depth of maximum shower) is

$$t_{\max} = \frac{a-1}{b}$$

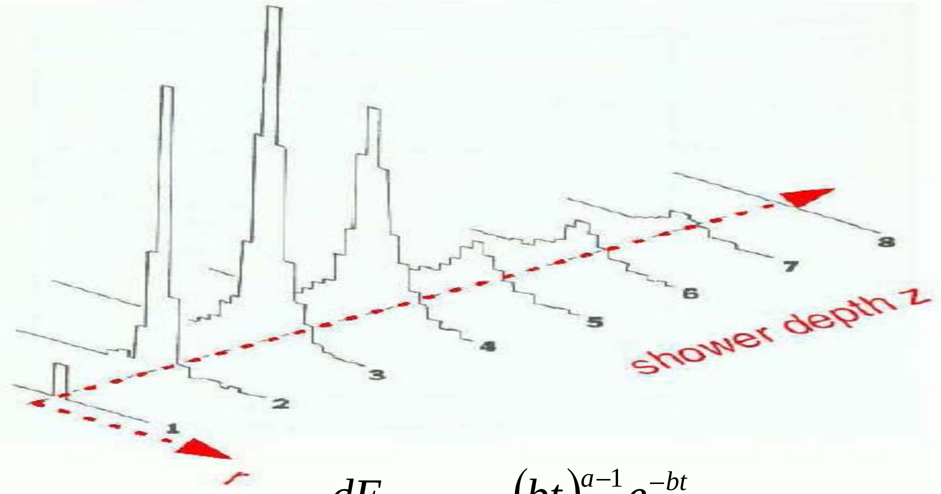
- The following formula was used to describe the **lateral profile**:

$$f(r) = \frac{6R^2 r}{(r+R)^4}$$

where *r* is the distance of a crystal to the shower center in some layer. And *R* is a parameter, which is related to the shower depth,

$$R = \mathrm{A}\left(\frac{\mathrm{t}}{\mathrm{t}_{\max}}\right)^2$$

where A is independent of the shower depth but related to the energy. **For a EM shower, A should be a fixed value for different layer and different crystal.**



$$\frac{dE}{dt} = E_0 b \frac{(bt)^{a-1} e^{-bt}}{\Gamma(a)}$$

$$f(r)dr = \frac{3}{\pi}\frac{R^2}{(r+R)^4}\cdot rdr\boxed{\int d\theta}^{2\pi}$$

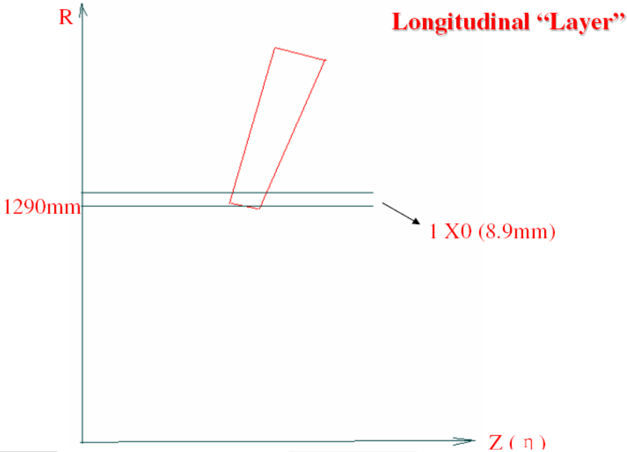
$$\int_0^{\infty} f(r)dr = 1$$

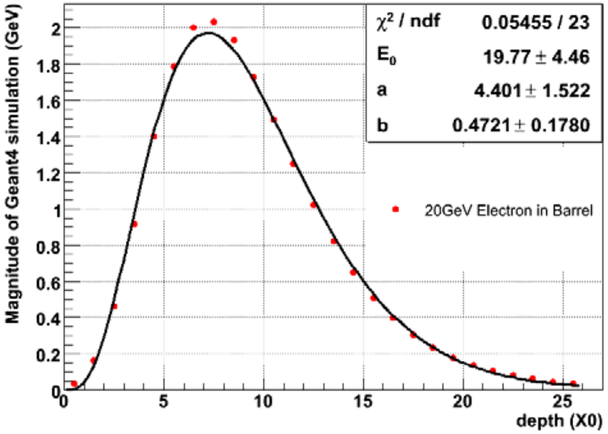
- The lateral formula was obtained from the ECAL Test Beam study in the **AMS (Alpha Magnetic Spectrometer) experiment**, in which the ECAL is consisted of 18 layers. So the lateral formula can be studied layer by layer to determine the parameter **R which changed with shower depth.**

EM Showers -- Longitudinal profile

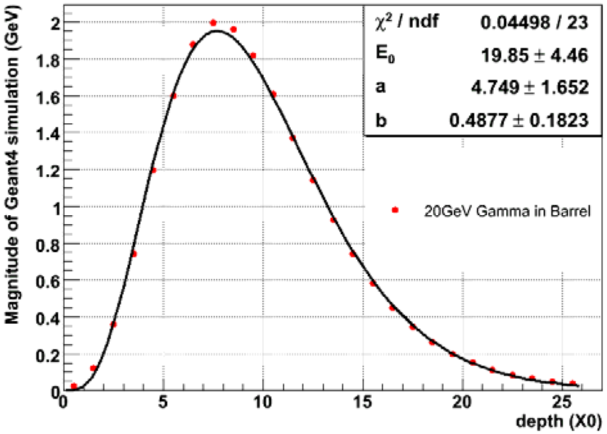
Determine longitudinal profile from CMS Geant4 Simulation

- Along the R(=√x2+y2) direction, from R=1290mm, about 26 layers are split in G4 Sim, with each layer about 1X0 .
- Simulation samples of single particles in SW167 with incident point: η =0.05, φ =0.22.
- Using “EcalSimHitsValidProducer” in the CMSSW/Validation package
- ~2000 evts/sample to see the average distribution

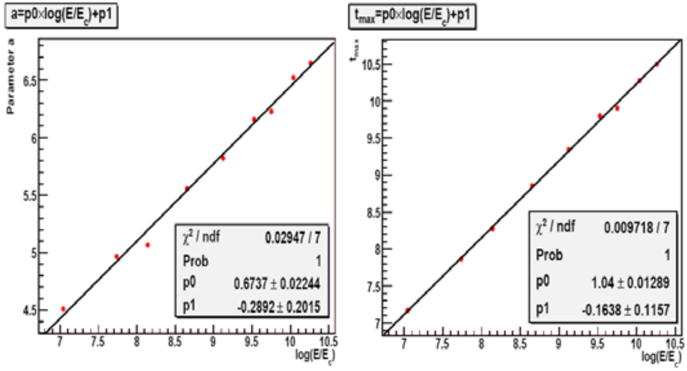




20GeV Electron longitudinal profile fitted by the Gamma-distribution



20GeV Gamma longitudinal profile fitted by the Gamma-distribution



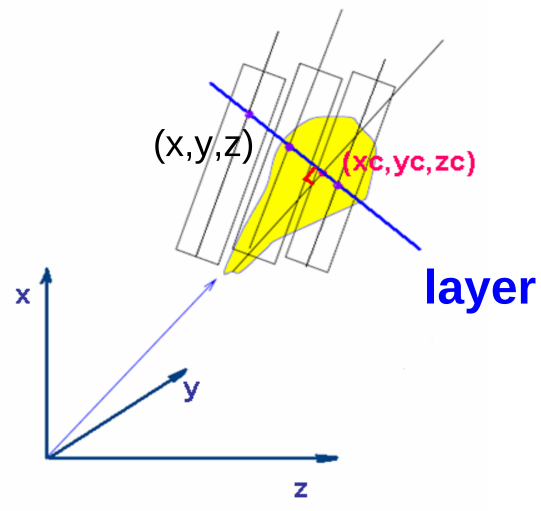
$$\frac{\mathrm{d}E}{\mathrm{d}t} = E_0 b \frac{(bt)^{a-1}\mathrm{e}^{-bt}}{\Gamma(a)}$$

Then the parameters a and b can be determined from the Geant4 study.

t=0 for the shower start point

Validation of the whole empirical formula

- The empirical formula was used to fit the energy deposit in each crystal, in a 5×5 crystal array around the maximum energy crystal.
- During the fitting process

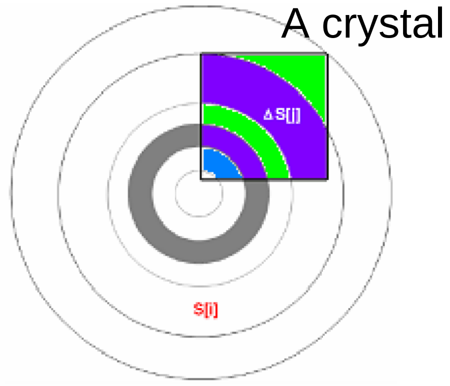


- Along the shower direction (line of COG obtained by the Energy Log-weighted method and the original point / vertex), the ECAL is divided into 26 layers. The energy of each "layer" can be obtained by the longitudinal formula (i.e., calculated from the Gamma-distribution, parameters a and b were fixed from the G4 sim. study).
- The parameter R in lateral profile of each "layer" can be written as the function of the fraction of the shower depth *t* over the maximum shower depth *tmax*.

$$R = \mathrm{A}\left(\frac{\mathrm{t}}{\mathrm{t}_{\mathrm{max}}}\right)^2$$

where A is the real fitting parameter.

- In each layer, the lateral formula (isotropy at the same *r*) and the areas between 2 circles (L3 method, more circles, higher precision, but more time needed) were used for the calculation of energy in each crystal. Then for each crystal, the sum energy of 26 layers was used as the fitting value, to compare with the energy deposit.
- MINUIT package in ROOT was used for the minimization of the $\chi 2$.

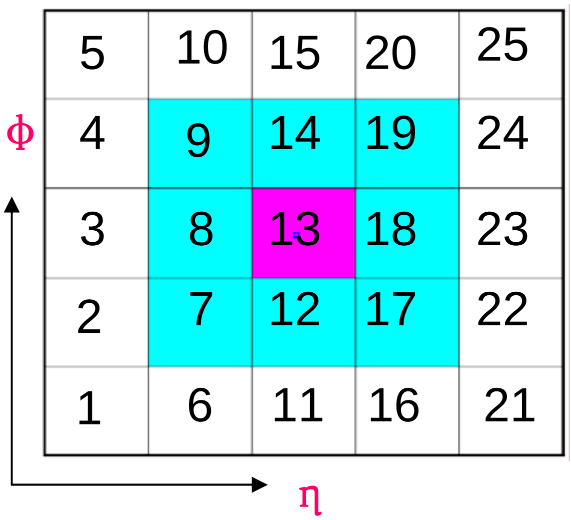


From r=0 to 20 cm, 100 circles were used. Much compact for the center crystals

$$\chi^2 = \sum_{icry=1}^{25}(E_{icry}^{fitted} - E_{icry}^{original})^2$$

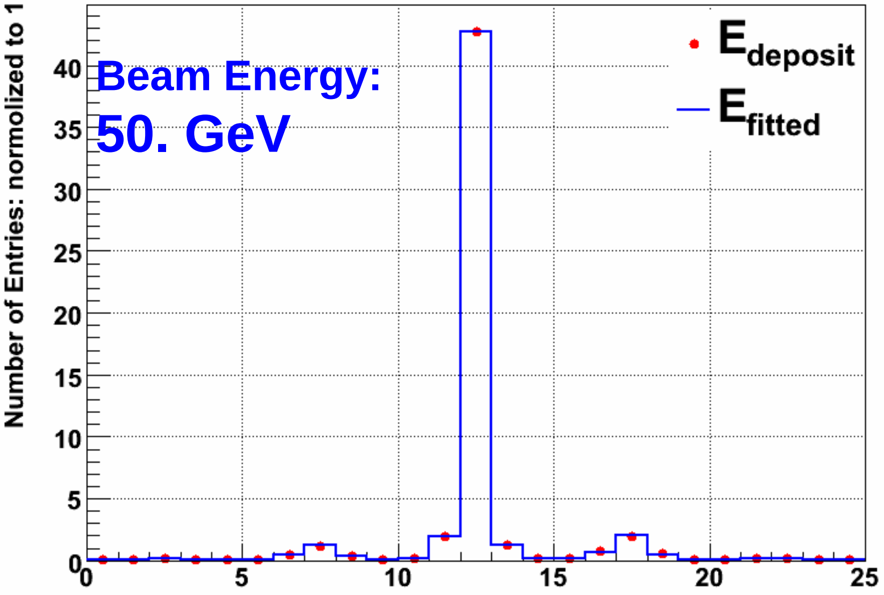
Fitting result of TB2006 Electron data

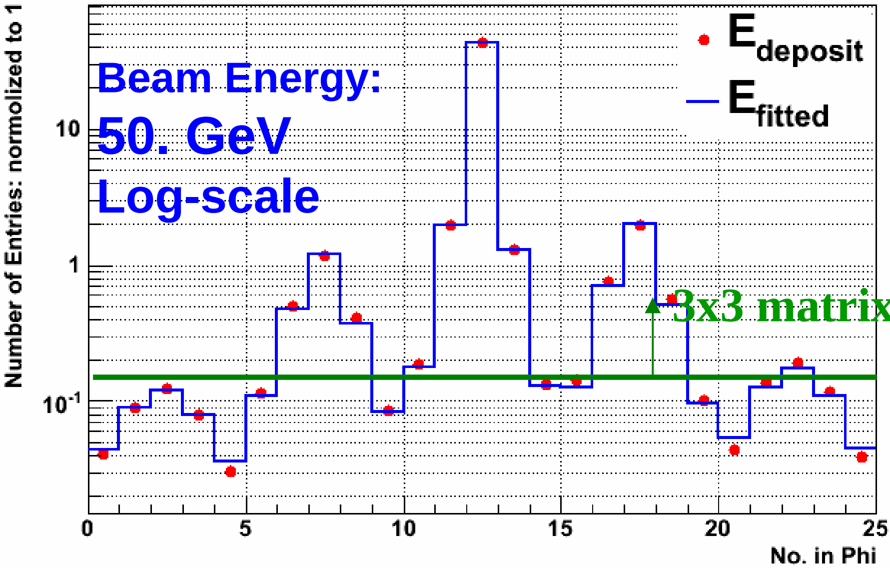
- The hodoscope cuts (±**2 mm**) were applied to select the calibrated test beam (electron) events which hit almost the same point in a crystal.
- Y axis: Averaged energy in each crystal with the statistic of ~ 10^3 events.
- X axis: The crystal numbered from 1 to 25.
- For the TB2006 data, the EM shower shape can be well fitted by the empirical formula.



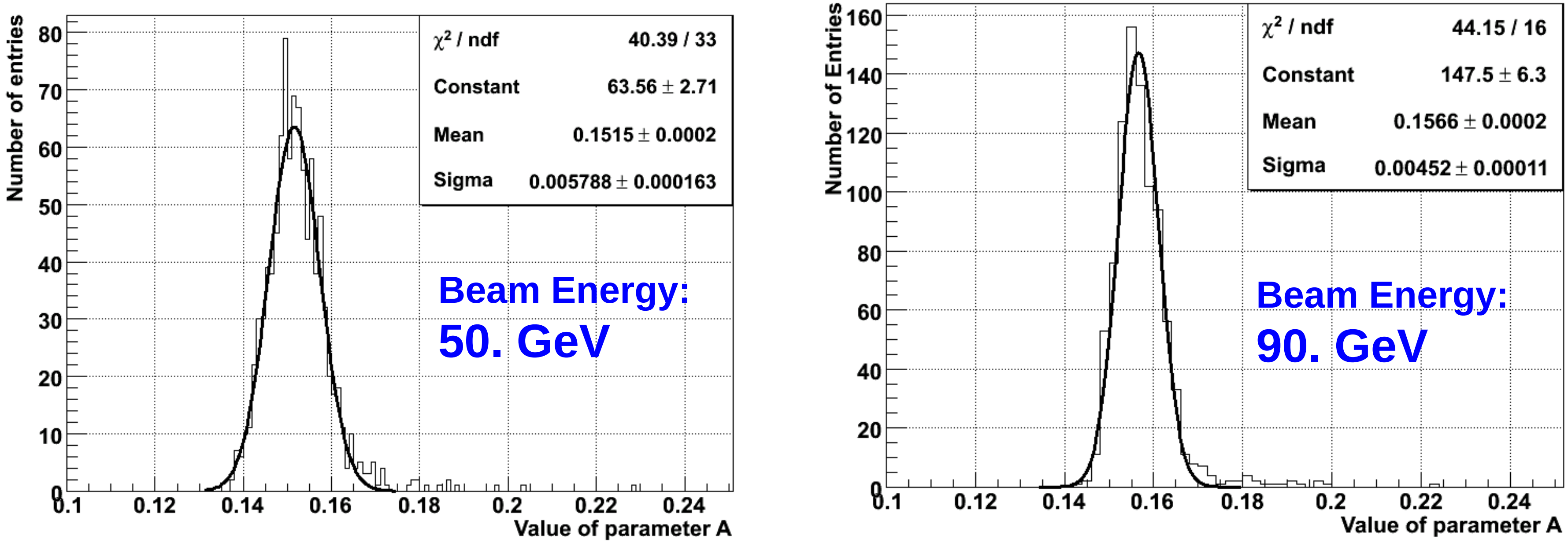
Crystal (or cell) number

5	10	15	20	25
4	9	14	19	24
3	8	13	18	23
2	7	12	17	22
1	6	11	16	21

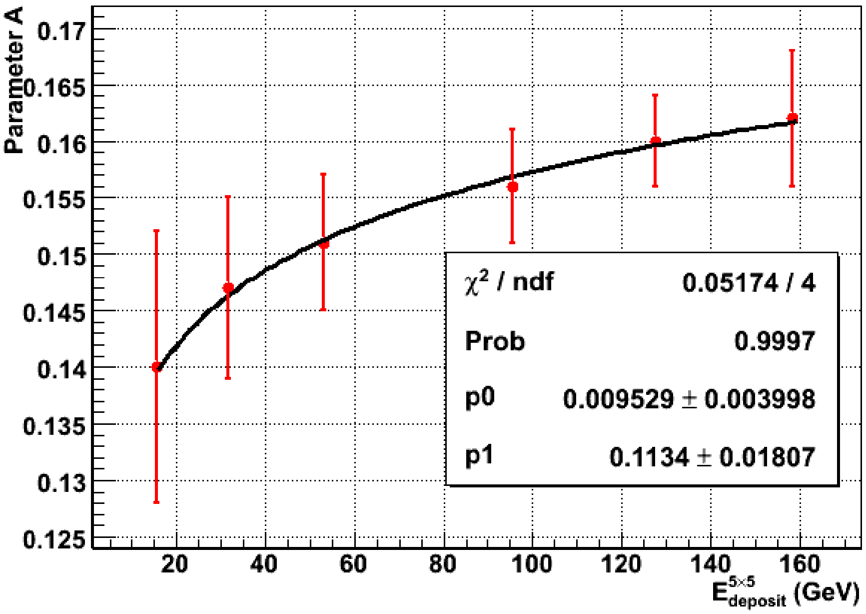




Fitting values of parameter A for TB2006 Electron



A distribution for different showers



Lateral profile

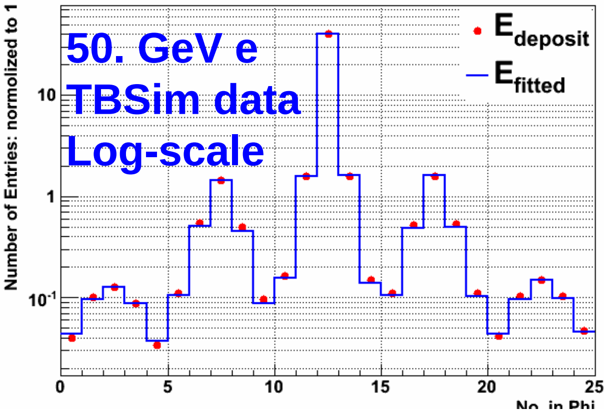
$$f(r) = \frac{6R^2 r}{(r+R)^4} \qquad R = \mathrm{A}\left(\frac{\mathrm{t}}{\mathrm{t}_{\max}}\right)^2$$

$$A = p0 \cdot \log(E) + p1$$

TestBeam Sim. & Full Sim. of electron

For the TestBeam Simulation

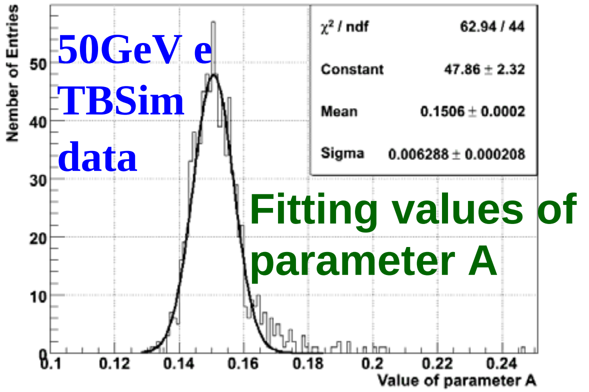
- With the same setup as ECAL test beam, samples of electrons were Sim. & Rec. with SW_167
- The same hodoscope cuts was used to select events: -2mm<X<2mm, -2mm<Y<2mm
- The formulae (Longitudinal + Lateral) can also well describe the EM shower of TB simulation e data



50. GeV e
TBSim data
Log-scale

For the Full detector simulation

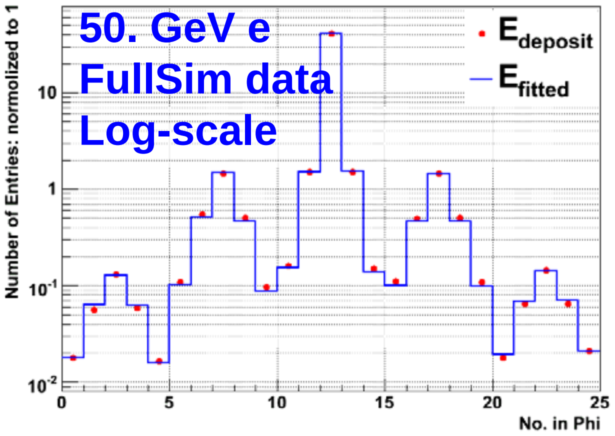
- Switch off the Magnetic Field.
- Using the same position of incidence as TBSim
- The formulae (Longitudinal + Lateral) can also well describe the EM shower of detector full simulation e data.



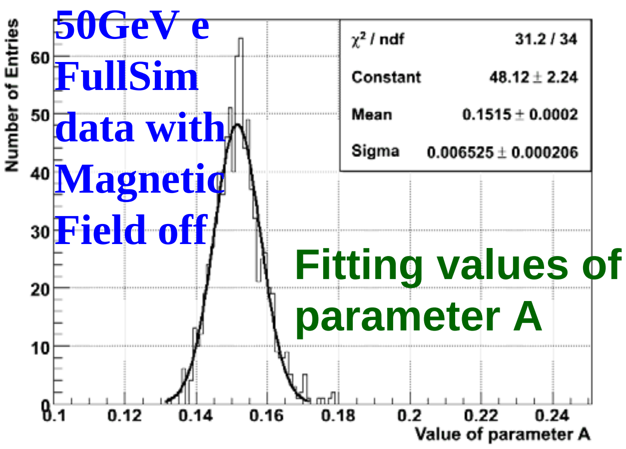
50GeV e
TBSim
data

Fitting values of parameter A

The results of the Test Beam, the TBSim and the FullSim are consistent.



50. GeV e
FullSim data
Log-scale



50GeV e
FullSim
data with
Magnetic
Field off

Fitting values of parameter A

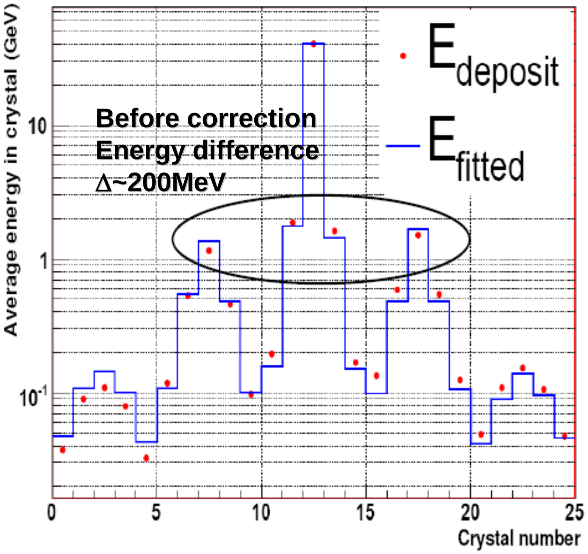
Lateral profile

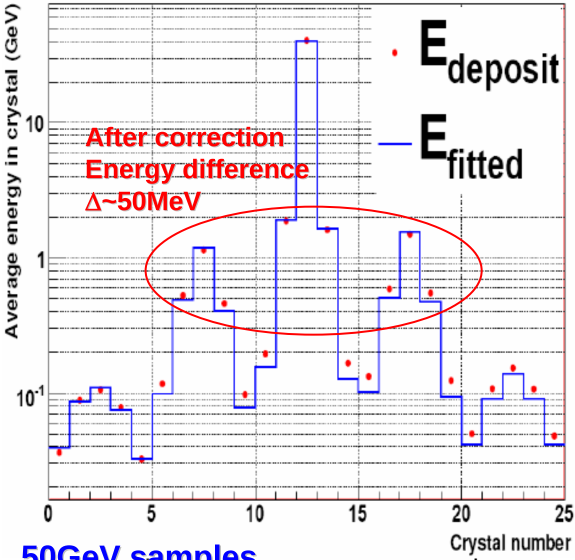
$$f(r) = \frac{6R^2 r}{(r+R)^4}$$

$$R = A\left(\frac{t}{t_{max}}\right)^2$$

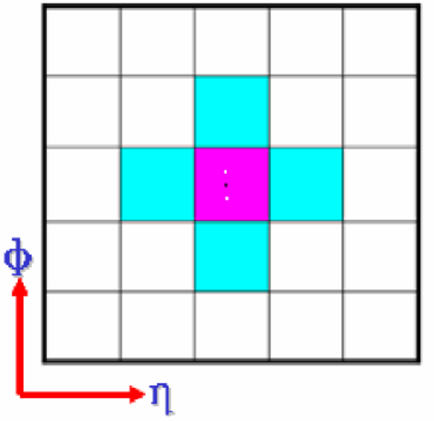
Formulae validation for the Photon Full Sim. Samples

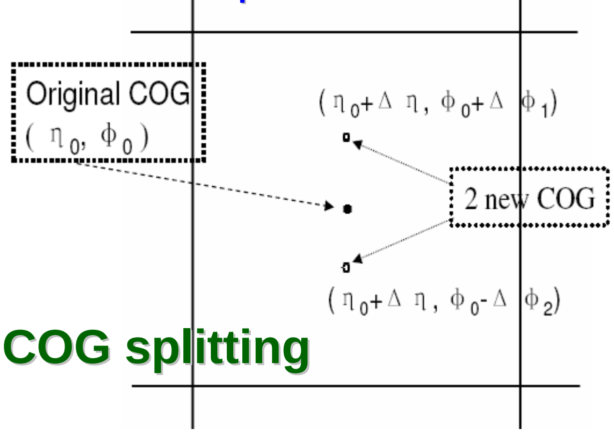
- For the Full Detector Simulation of Gamma EM shower with B-on, the energy spreading is, to good approximation, only in the φ-direction.
- For the isotropy at the same r of the lateral formula in a layer, the process method needs to be corrected.
- Correction: The original COG obtained by the energy Log-weighted method is split into 2 new COG points; 2 interaction points with a layer are obtained; In a layer, the energy in a crystal is obtained from the average effect of the lateral formula originated at the 2 interaction points





50GeV samples





COG splitting

- There are **5 variables** during the formula fitting: 3 parameters of the new COGs (Δη, Δφ1, Δφ2), parameter *A* in the lateral formula and parameter *E0 (total energy)*.
- The fitting result after correction is satisfactory (see the top plots).

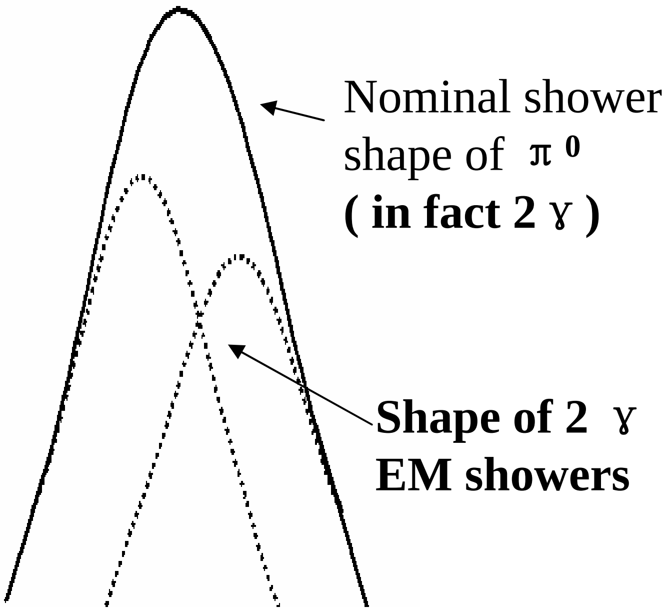
Application of parametric EM shower method (I) :

γ / π^0 discrimination for the UNconverted case in ECAL Barrel

Result of γ / π 0 discrimination from the method directly

- Introduction of the first idea (directly EM shower fitting): For a EM shower (the seed of a reco. photon candidate)
  - ✓ **First fitted by the parameterized formula of 1 EM shower**
  - ✓ **Then fitted by the parameterized formulae of 2 EM showers**
  - ✓ **Compare the χ^2 of the 2 fitting processes.**
  - ✓ **If the fitting result with 2 EM showers is better, then calculate the invariant mass of the 2 EM showers.**
  - ✓ **If the invariant mass locates close to the π^0 mass peak, then the shower is a π^0.**
  - ✓ **Else it is a γ.**

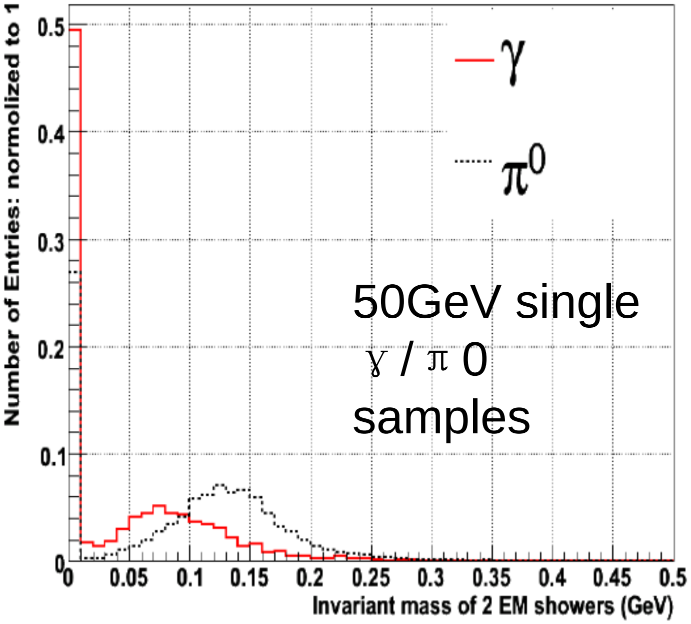
- The result is not so good as expected. And lots of time is needed for the 2 fitting processes. It’s not so convenient for application.



Nominal shower shape of π^0

(in fact 2 γ)

Shape of 2 γ EM showers



50GeV single γ / π 0 samples

Energy (GeV)	Pi0 rejection eff. for keeping 90% Gamma efficiency
20	64.1
30	61.1
50	38.3
80	14.6

TMVA_BDT method - combining the results of 1 EM shower fitting & Artifical NN inputs

- For the fitting results with the parameterized formula of 1 EM shower, 6 variables were considered: ***A***、 **ΔE/Edep5x5 where ΔE=E0-Edep5x5**、**Δη**、**Δϕ1**、**Δϕ2**、 **χ2**

- For the unconverted case in Barrel, **12 variables** were used as ANN inputs in CMS AN-2008/063 (K. Karafasoulis and A. Kyriakis)

$$p_6 = \frac{S_4}{S_{25}}, p_4 = \frac{S_1}{S_9}, p_5 = \frac{S_9 - S_1}{S_{25} - S_1}$$

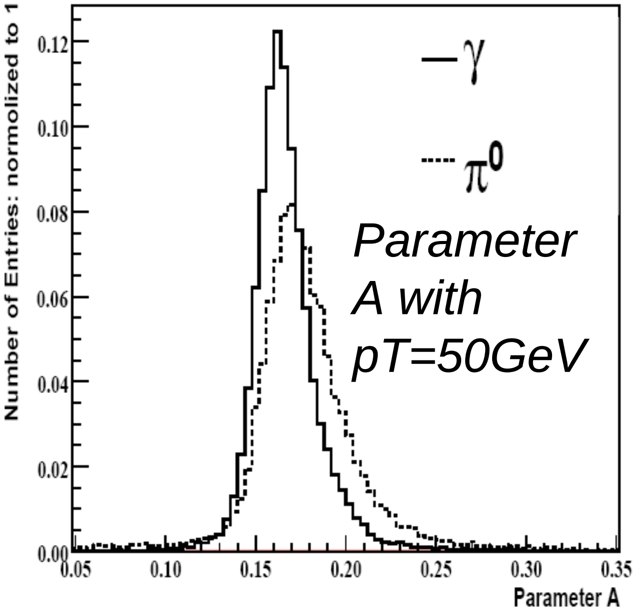
$$p_{12} = \frac{M_2 + S_1}{S_4}, p_9 = \frac{S_6}{S_9}, p_{11} = \frac{M_2 + S_1}{S_9}, p_8 = S_{6-ratio}$$

$$p_1 = |x_{cog}|_{25} = \left|\frac{\sum_{i=1}^{25} E_i X_i^{rel}}{S_{25}}\right|, p_7 = |y_{cog}|_{25} = \left|\frac{\sum_{i=1}^{25} E_i Y_i^{rel}}{S_{25}}\right|$$

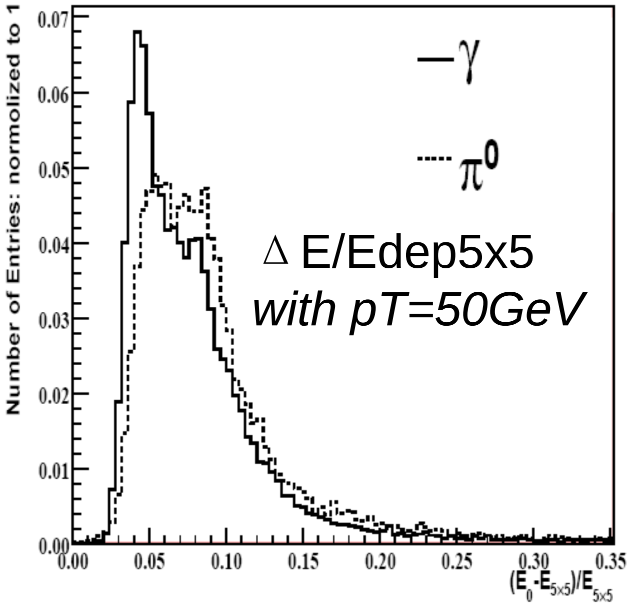
$$p_2 = \frac{\sigma_{\eta\eta}}{0.0004}, p_3 = \frac{\sigma_{\phi\phi}}{0.001}$$

$$\lambda_{\pm} = \frac{\sigma_{\eta\eta} + \sigma_{\phi\phi} \pm \sqrt{(\sigma_{\eta\eta} - \sigma_{\phi\phi})^2 + 4\sigma_{\eta\phi}^2}}{2}$$

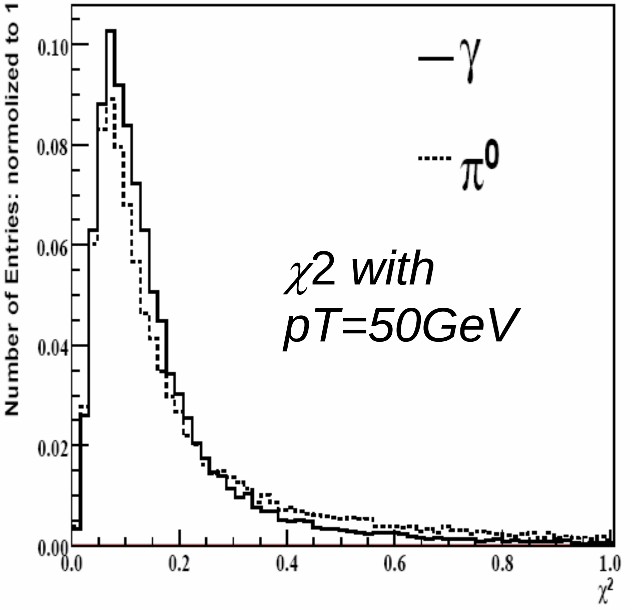
$$p_{10} = \frac{\lambda_-}{\lambda_+}$$



Parameter A with pT=50GeV



ΔE/Edep5x5 *with pT=50GeV*



χ2 with pT=50GeV

TMVA_BDT analysis result of combining the results of shower fitting and ANN inputs

- For keeping 90% Gamma efficiency, the Pi0 rejection efficiency with TMVA_BDT method is listed in the table as follows.

ET (GeV)	6 new variables	12 ANN inputs	Combined 18 inputs
20	54.2	73.7	75.1
30	55.0	59.5	65.5
40	47.0	52.9	59.4
50	38.0	41.0	48.2
60	32.0	34.8	39.1
70	25.6	28.7	33.9

- For the ET range we are interest in , 40-70GeV, for Higgs to GammaGamma analysis, **the π^0 rejection improved by ~6%**, using all the 18 variables for inputs than the only 12 inputs.

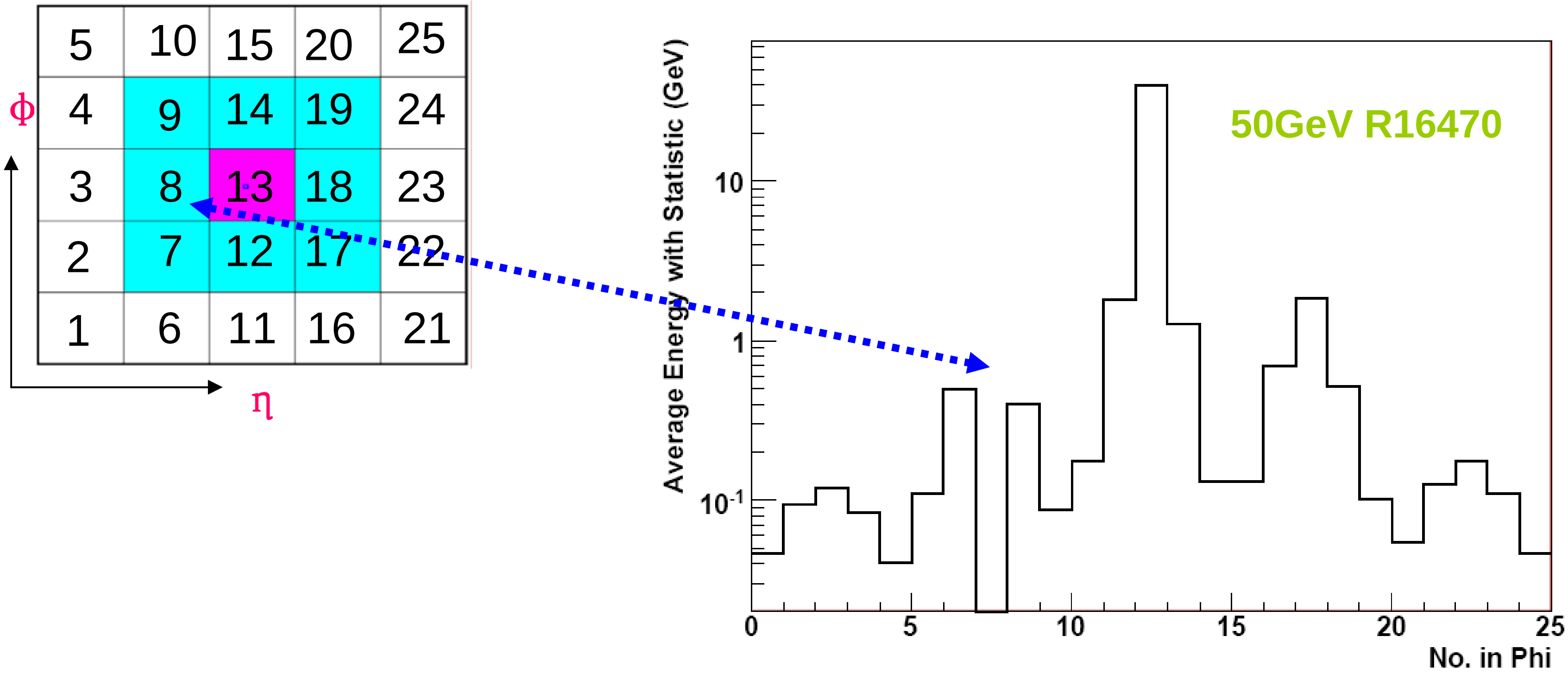
Application of parametric EM shower method (II) :

Dead channel correction in ECAL Test Beam

Artificial dead channel

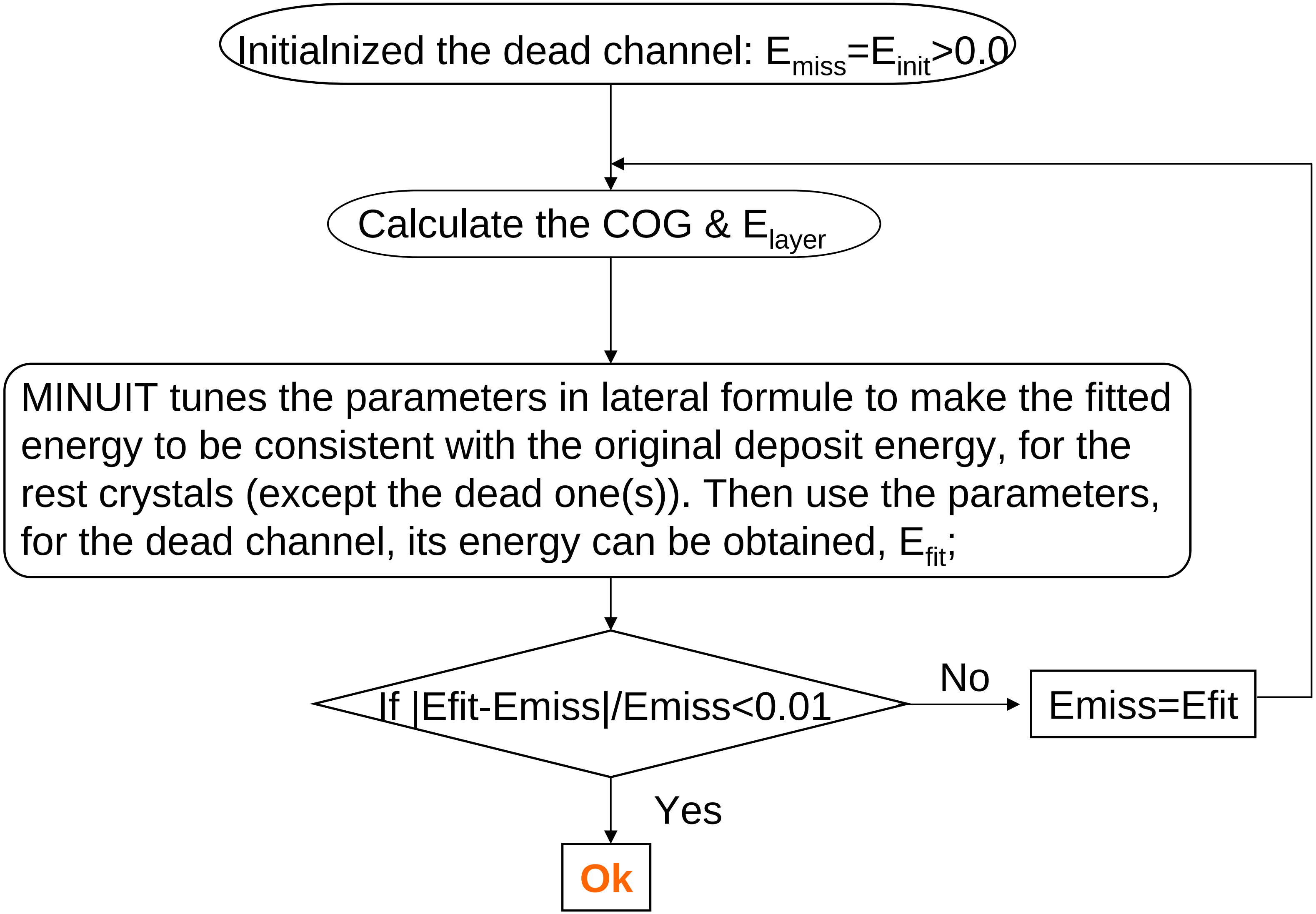
- The hodoscope cuts (±**2 mm**) were applied to select **the calibrated test beam 2006 ECAL (electron) events**.
- The energy of crystal no. 8 was set to be 0.

Crystal (or cell) number



5	10	15	20	25
4	9	14	19	24
3	8	13	18	23
2	7	12	17	22
1	6	11	16	21

Iterative Fitting Process of dead channel correction



Initialnized the dead channel: $E_{miss}=E_{init}>0.0$

Calculate the COG & E_{layer}

MINUIT tunes the parameters in lateral formule to make the fitted energy to be consistent with the original deposit energy, for the rest crystals (except the dead one(s)). Then use the parameters, for the dead channel, its energy can be obtained, E_{fit};

If |Efit-Emiss|/Emiss<0.01

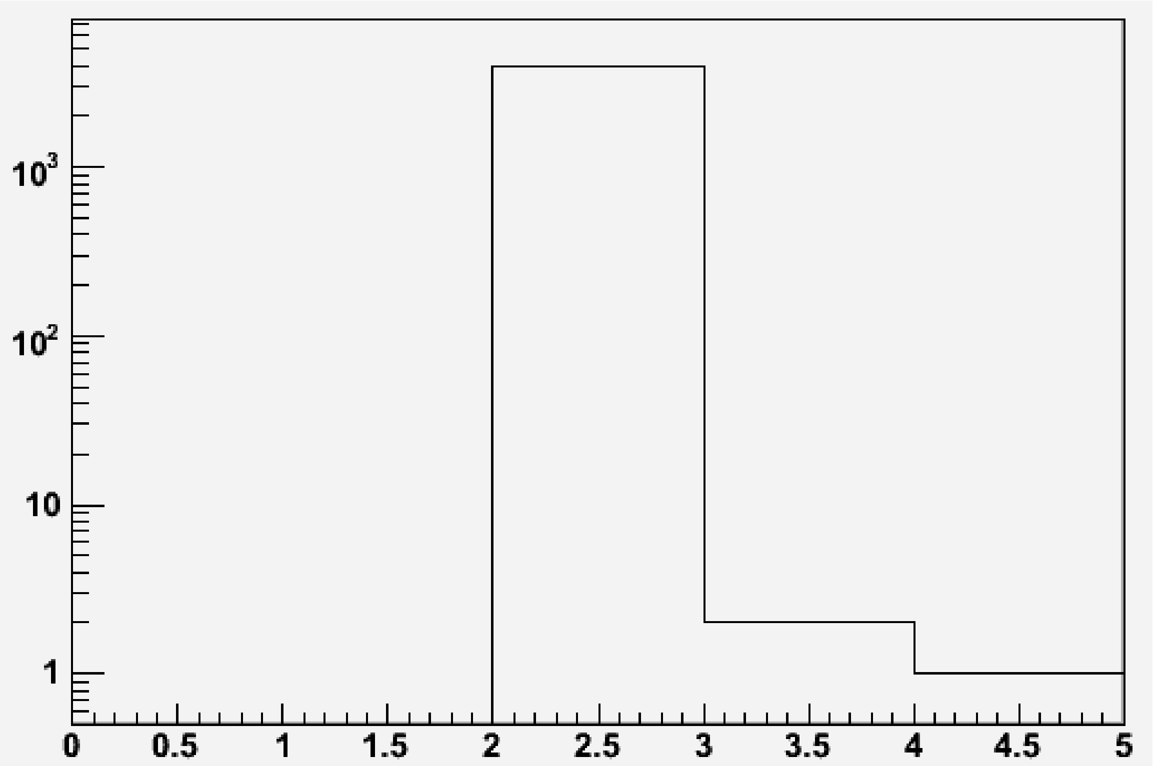
No

Emiss=Efit

Yes

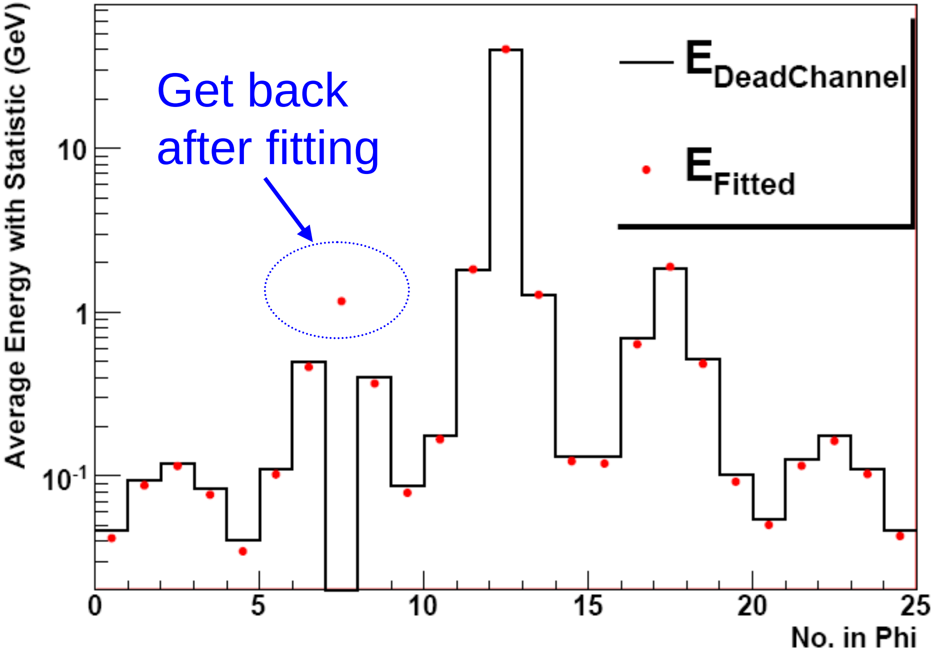
Ok

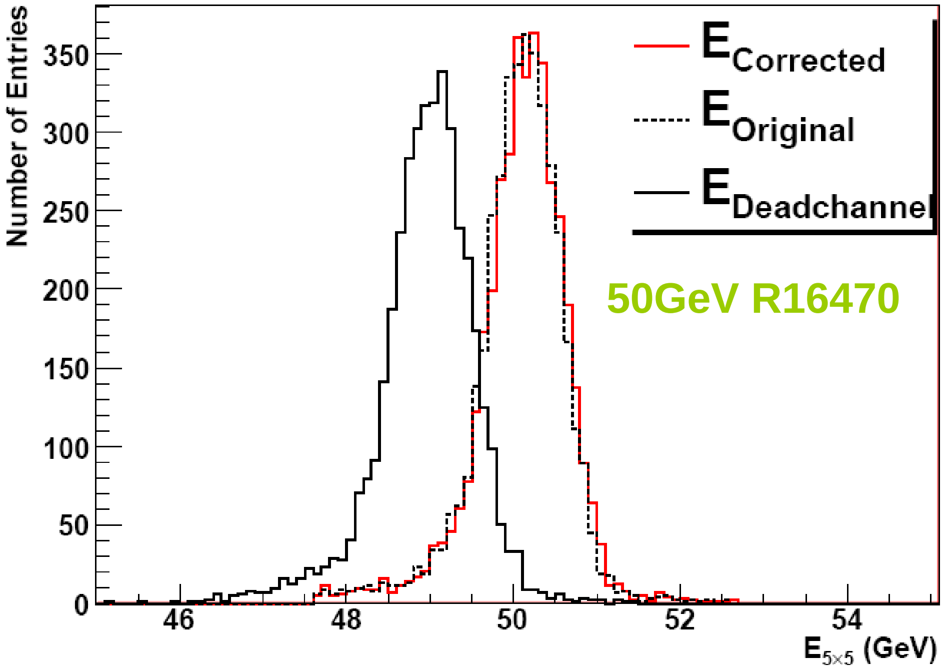
NLOOP of Iterative Fitting Process



For most events (showers), 2 loops are needed for the dead channel correcton

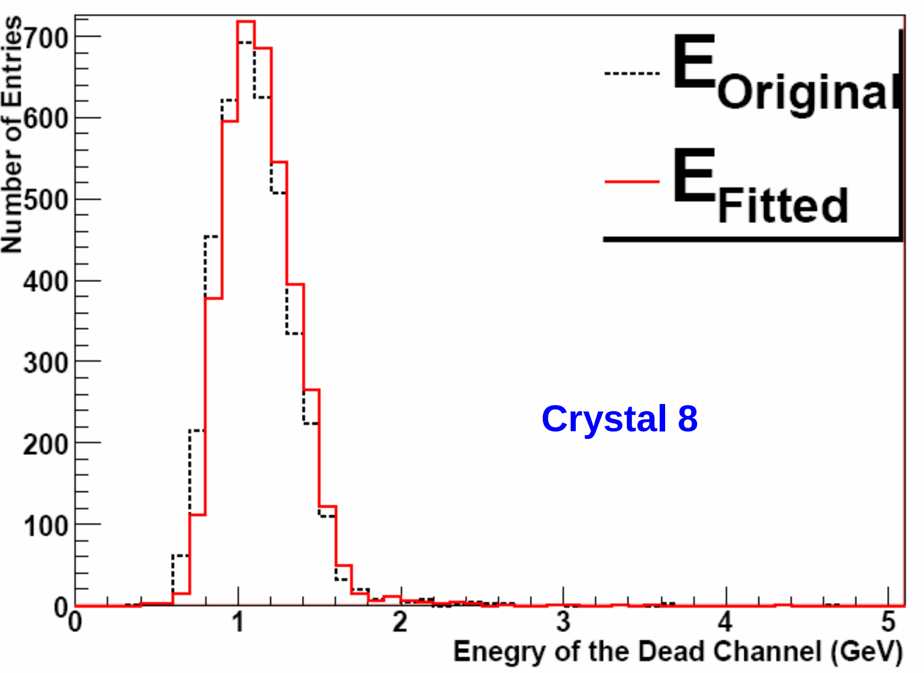
Results of dead channel correction

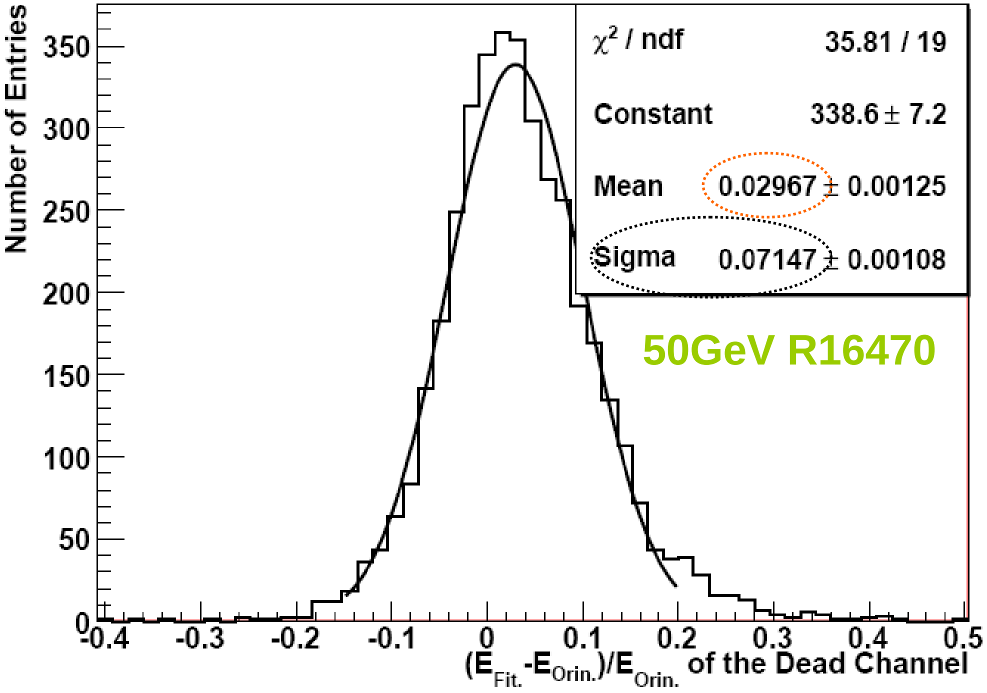




Red line: Total energy after dead channel correction

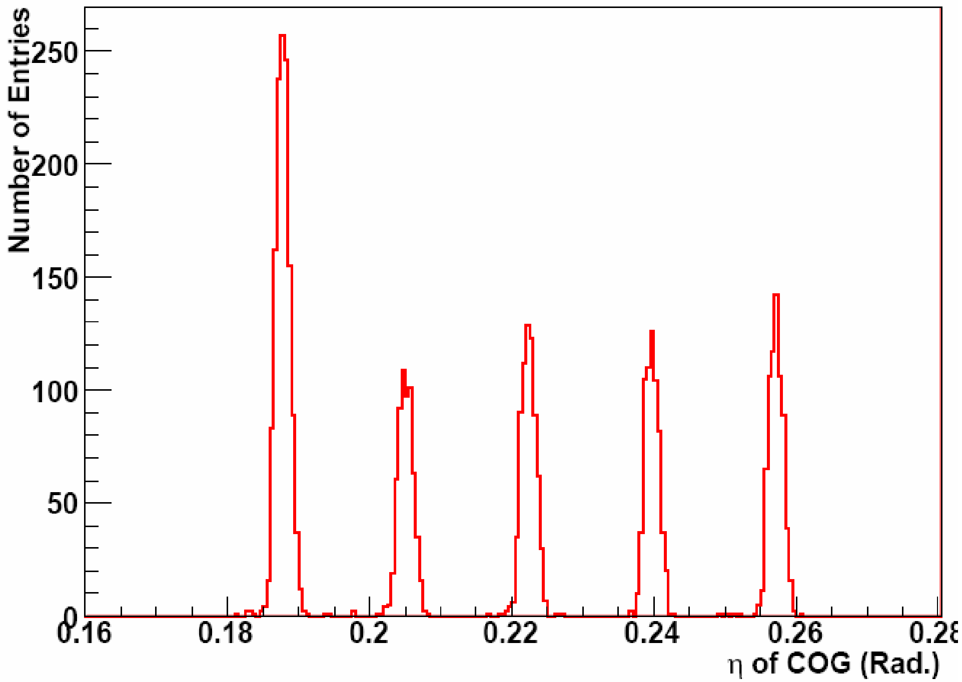
Results of the dead channel

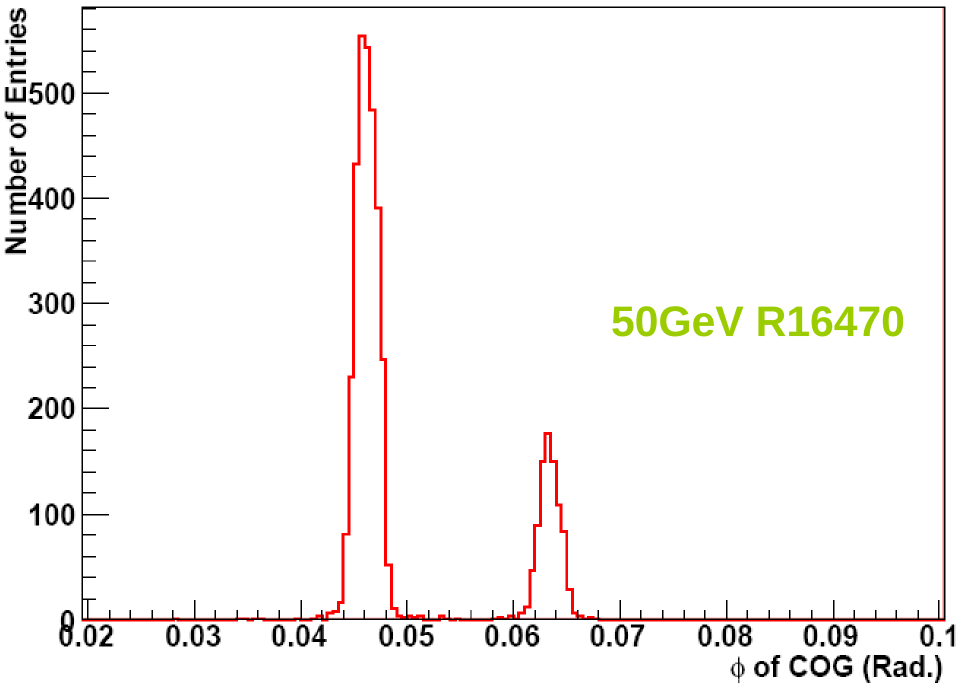




For the dead channel (crystal 8), the correction tend to overestimate, ~3% higher than the original depisot energy.

Reconstructed the center of gravity

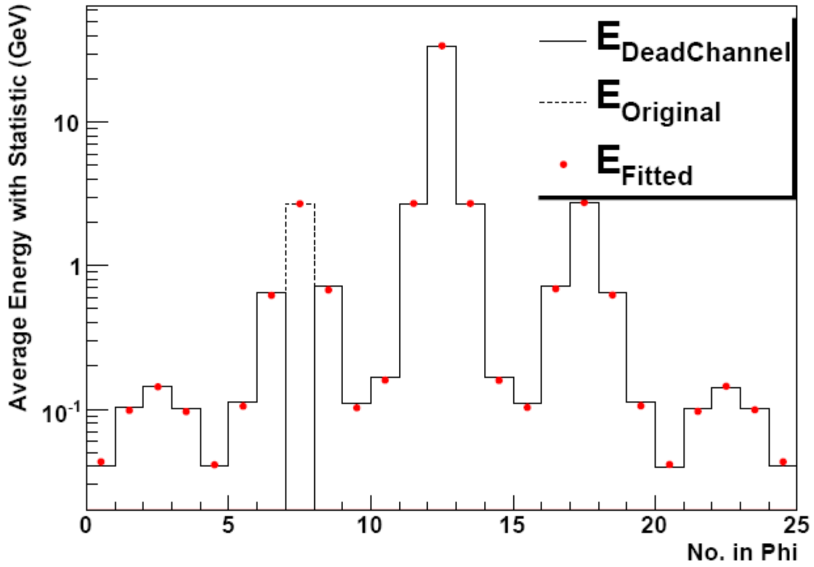


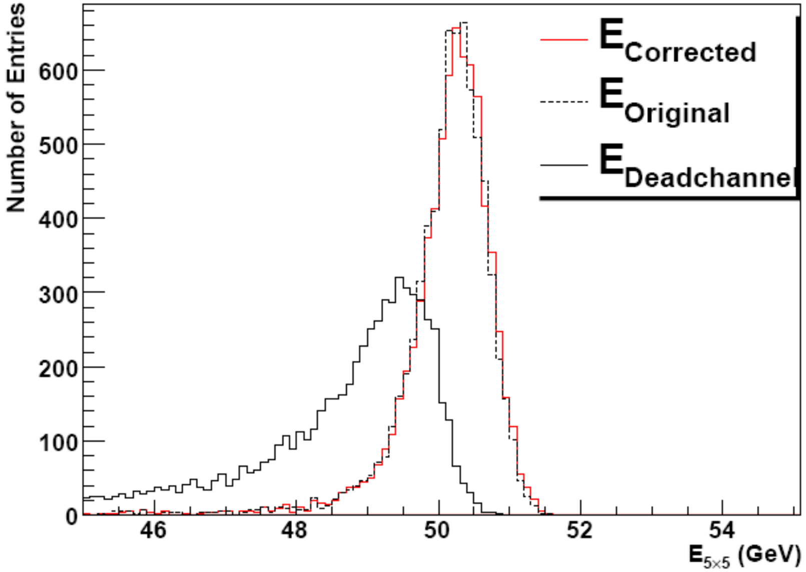


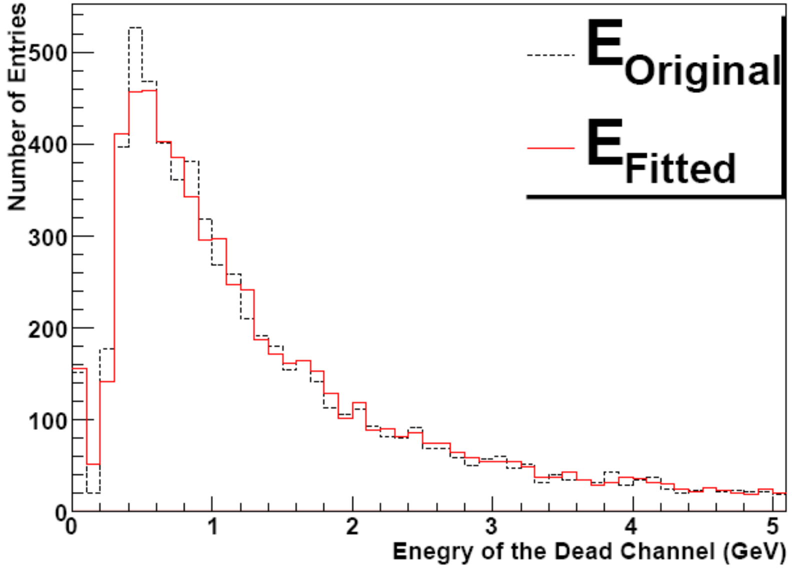
The COG can be also obtained.

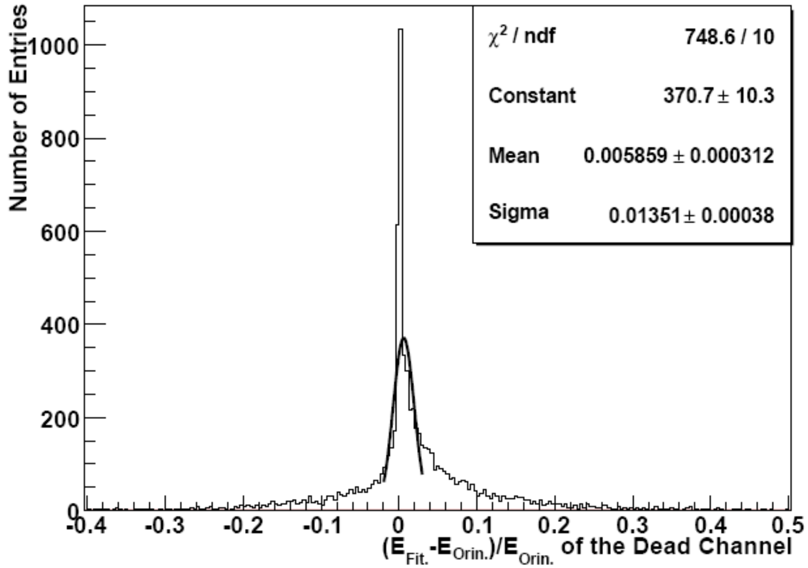
Results with Gamma MC sample in EB with EcalOnly

1. **50GeV Single Gamma MC samples with ParticleGun in ECAL Barrel and EcalOnly with Magnetic off.**
2. **5×5 crystal array around the maximum energy deposit crystal was used. The energy of crystal 8 was set to be 0.**
3. **Same method, but different parameters, a,b in logitudinal and A in lateral. (For different type of particles, e/γ)**









Summary

- An empirical formula wer used to describe the EM shower shape. With the data of CMS Geant4 and ECAL TB2006, we validate this formula. The result is satisfactory.
- The formulae can also well describe the EM shower of TBSim & detector FullSim data. The results of the Test Beam, the TBSim and the FullSim of electron samples are consistent.
- Considering the effect of magnetic field, the formulae can also well describe the EM shower of Gamma FullSim samples after the correction.
- **Combining the results of the EM shower fitting and ANN inputs,** the π^0 rejection can be improved by ~6%, for the ET range we are interest in , 40-70GeV, during the analysis of $\mathbf{H}\rightarrow\gamma\gamma$.
- The energy of dead channel can be **compensated** with the shower shape method.

Plan

for the dead channel correction

- To understand the difference of the result between TB2006 electron data and Gamma Ecalonly MC sample. Firstly try to run with the Electron MC sample to see the results.

- Try to find a common sample to run on to compare with the NN method Stepyanie used.

- Try to get results for side and corner crystals in addition to center.

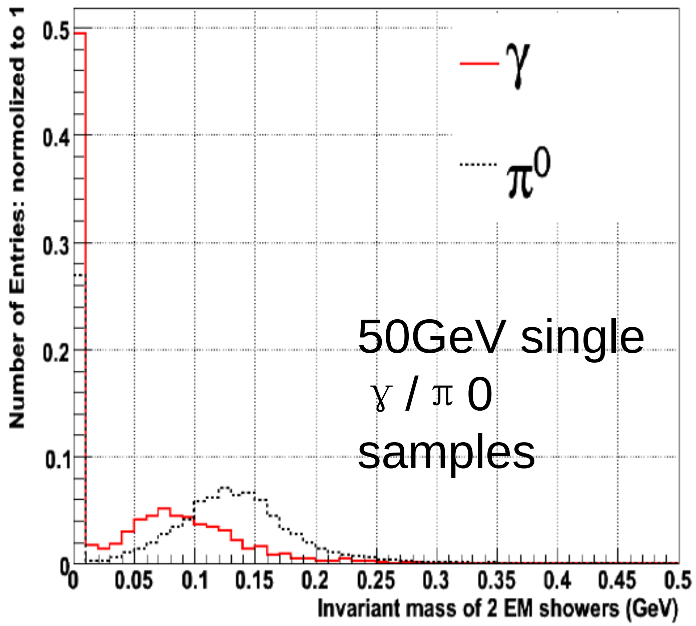
Merci 谢谢

Thanks

Backup

Result of γ / π 0 discrimination from the method directly

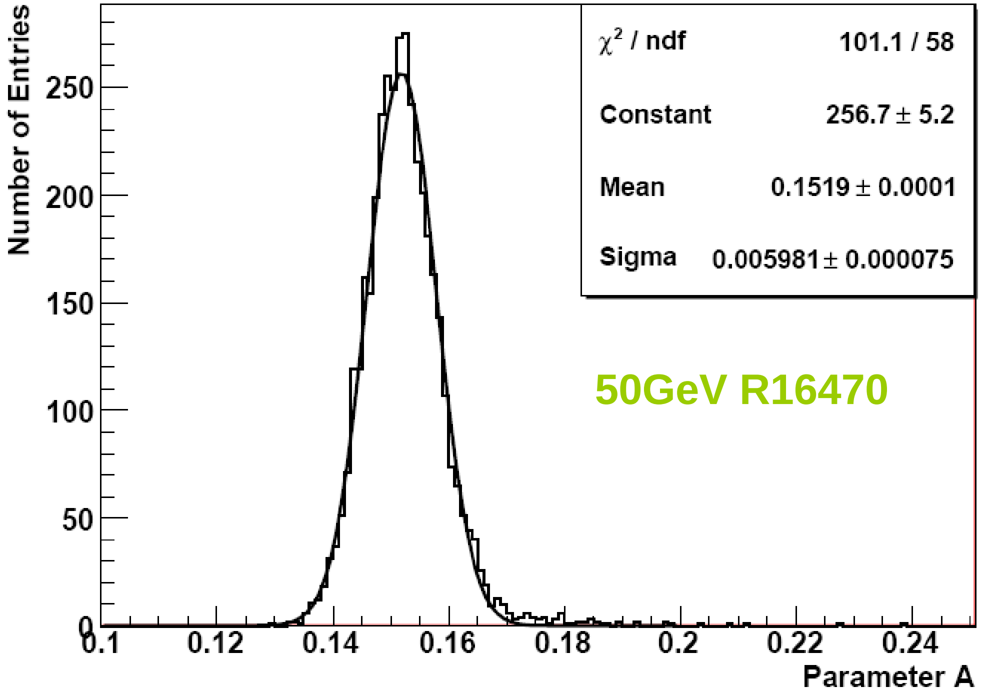
- Review of the Method: for a EM shower (the seed of a photon candidate)
  - ✓ First fitted by the parameterized formula of 1 EM shower
  - ✓ Then fitted by the parameterized formulae of 2 EM showers
  - ✓ Compare the χ^2 of the 2 fitting processes.
  - ✓ If the fitting result with 2 EM showers is better, then calculate the invariant mass of the 2 EM showers.
  - ✓ If the invariant mass locates close to the π^0 mass peak, then the shower is a π^0.
  - ✓ Else it is a γ .
- Must consider the probability of successful fitting. If the 2 fitting processes failed for the same EM shower, then the invariant mass is 0.
- The probability of the 2 fitting processes succeed for the same shower: ~60% (for 50GeV samples).
- Lots of time is needed for the 2 fitting processes included. It’s not so convenient for application.



50GeV single γ / π 0 samples

Energy (GeV)	Pi0 rejection eff. for keeping 90% Gamma efficiency
20	64.1
30	61.1
50	38.3
80	14.6

Parameter A in TB dead channel corection



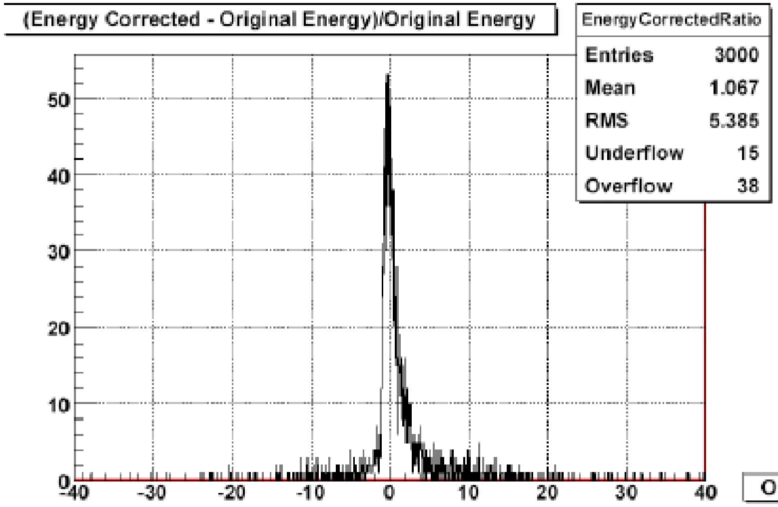
Be consistent with the result of the case when no dead channel, see slide 8.

TB2006 Calibration for SM6:
/afs/cern.ch/cms/ECAL/testbeam/pedestal/2006/CALIBRATIONS/CMSSWcalibCoeff_SM6_TBH4_S1_V00-01-00.txt

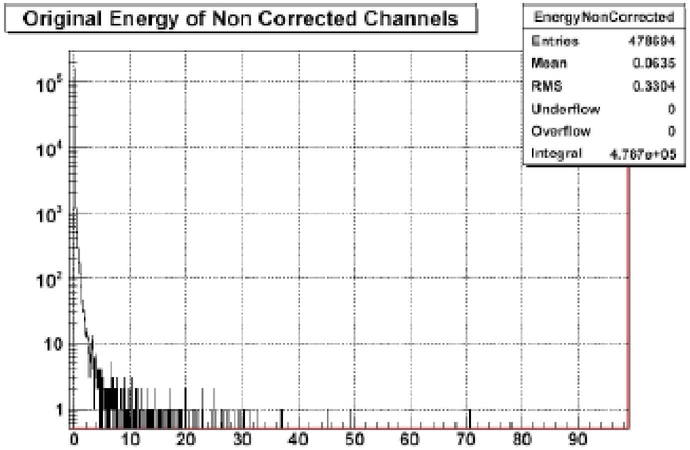
Result from S. Beauceron, 2009.04.30

Z→ee MC sample ?

Looking at single channels



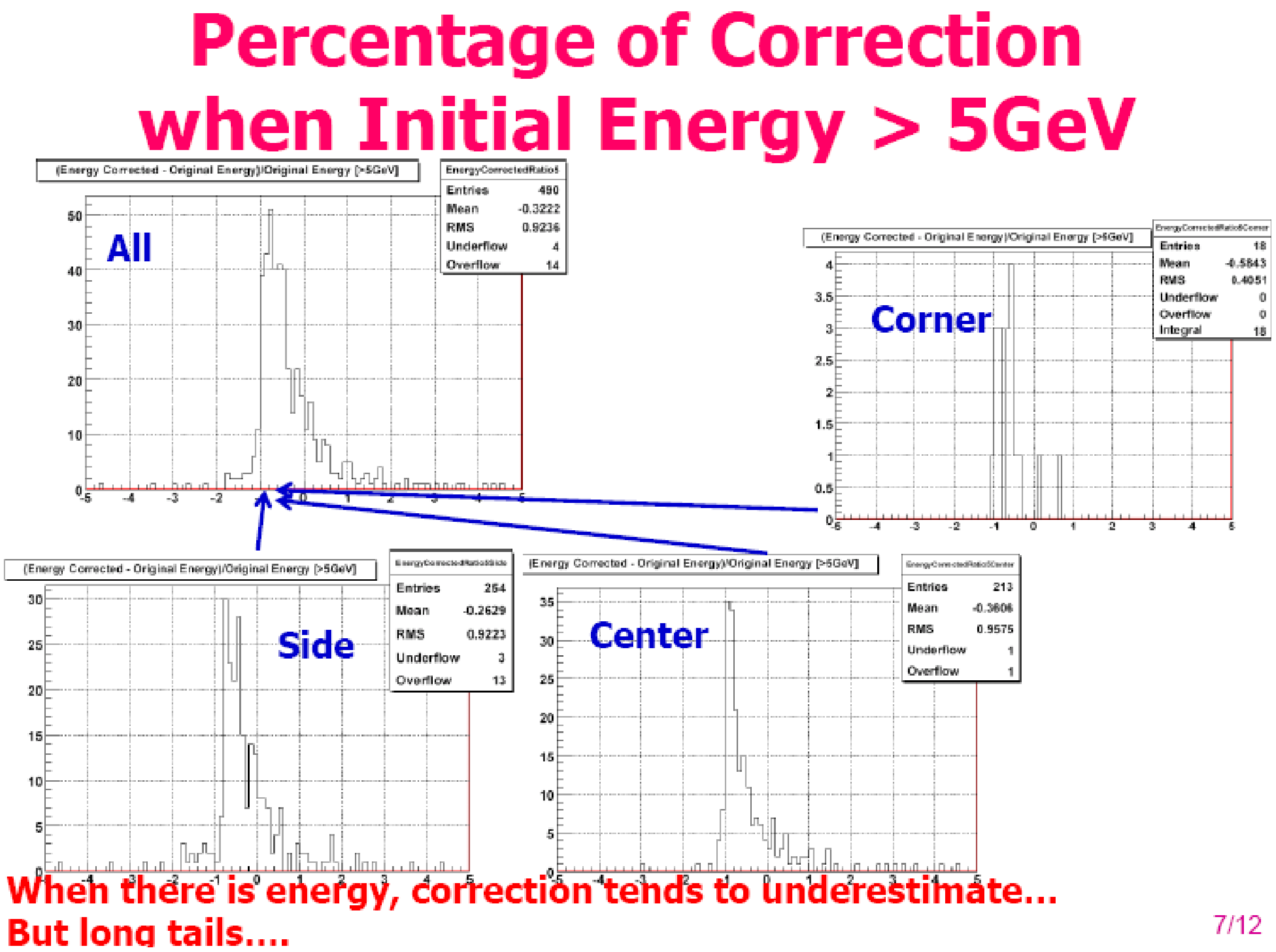
Over more than 480k, only 3k have a sum8> 8 GeV
→ Make sense



8 GeV is not a stupid threshold…
Only 1406/478694 = 0.3% channel have more than 1 GeV and are not corrected

Result from S. Beauceron, 2009.04.30

Z→ee MC sample ?



Percentage of Correction when Initial Energy > 5GeV

When there is energy, correction tends to underestimate…
But long tails….

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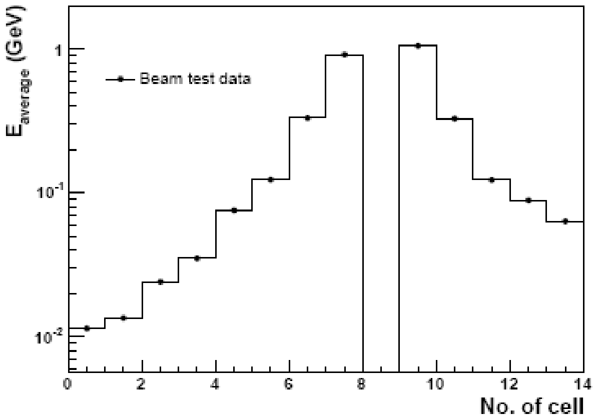
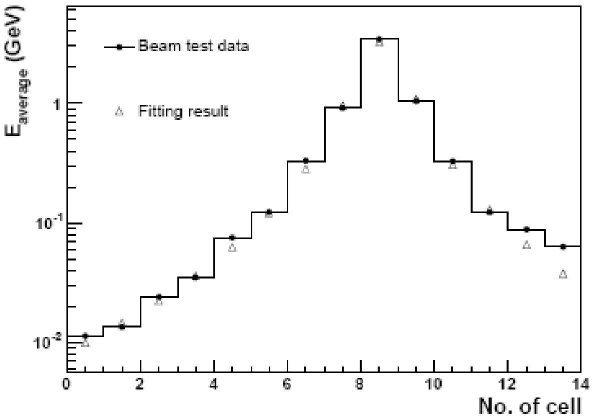
Correction of Bad PMTs' readout at AMS

- Assume that there are some man-made bad PMTs in the ECAL 2002 test beam.
- The bad PMTs' readout can be obtained after fitting using the empirical formula.

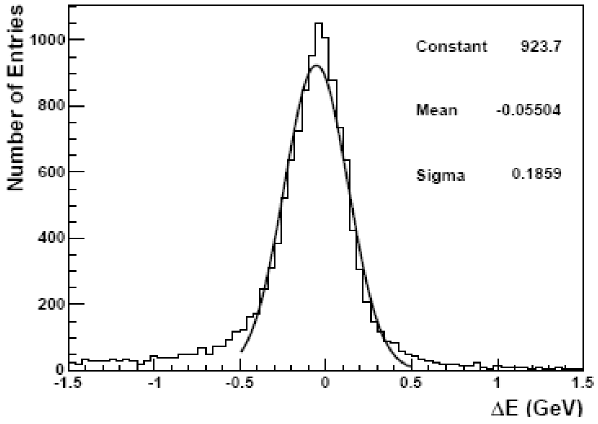


(a)

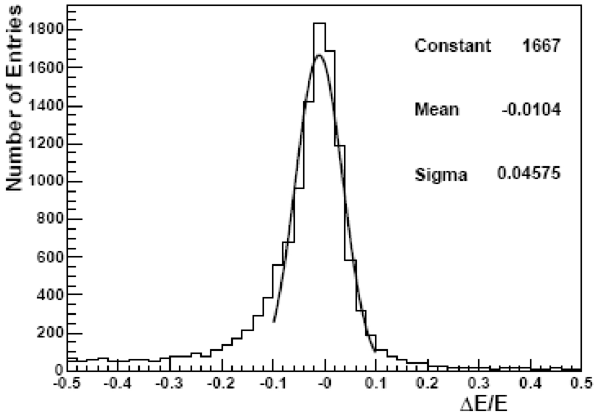


(b)

Compensation of the man-made bad PMTs‘ readout.



(c)



(d)