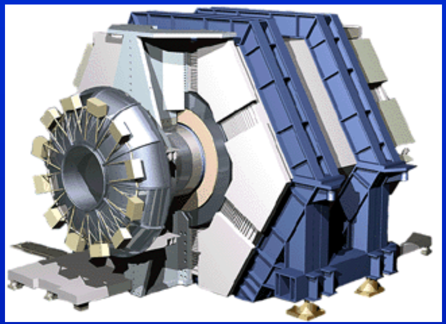
Calor 2008, Pavia

May 30th 2008

Calibration of the *BABAR* CsI (Tl) Calorimeter

Jörg Marks
University of Heidelberg

for the



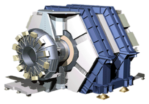
Calorimeter Group

of the

BABAR Collaboration

Introduction

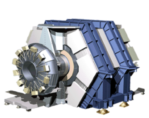
- γ energy calibration steps
  - Electronics calibration
    Determine pedestal and overall gain by precision charge injection into the preamp input
  - Charge to energy conversion on the crystal level
    Correct for time dependent light yield changes due to radiation.
    Nonuniformity of the light yield change requires calibration at different E
    → 6.13 MeV γ's from a radioactive source
    → $e^+ e^- \rightarrow e^+ e^-$ (3-8 GeV)
  - Cluster energy calibration
    Emphasis: relate $E_{cluster}$ deposited by the shower to E(e) or E(γ)
    Correct for energy leakage, energy loss in dead material and energy not associated with the cluster
- Outline
  - ✓ Cluster calibration scheme
  - ✓ Low and high Eγ calibration validation
  - ✓ Improve data description by MC
  - ✓ Lateral non uniformity correction
  - ✓ Association of EMC and DIRC info



Cluster Energy Calibration Scheme

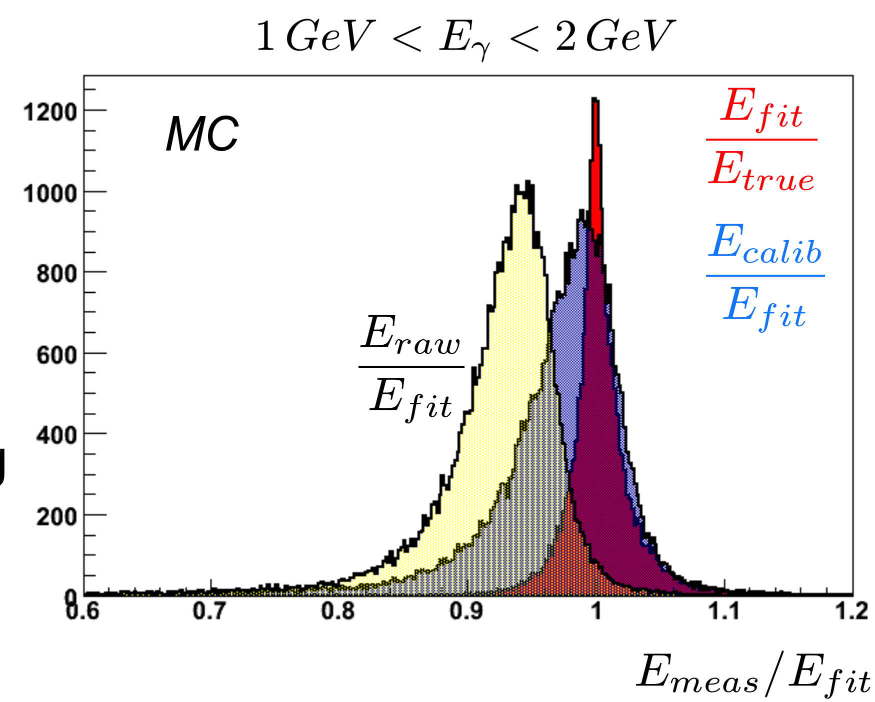
- The γ energy calibration
  - Determine the γ energy calibration in the EMC by using 2 different processes
    - Symmetric π^0's ($\pi^0 \to \gamma\gamma$) from $e^+e^- \to hadrons$ $\quad 70\,MeV < E_\gamma < 2\,GeV$
    - γ's from $e^+e^- \to \mu^+\mu^-\gamma$ $\quad 400\,MeV < E_\gamma < 6\,GeV$
  - Need to measure the calibration function $C_\gamma = f(E_\gamma, \theta_\gamma)$

    Poor coverage of the parameter space, therefore use $C_\gamma = g(E_\gamma) \cdot h(\theta_\gamma)$
  - Determine the functional form of C_γ in data and MC simulation
  - Emphasis:
    - correct absolute energy scale
    - simulation describes the data
- The calibration concept
  - Measure $h(\theta_\gamma)$ of C_γ in 3 bins of $E_\gamma > 500\,MeV$ using $e^+e^- \to \mu^+\mu^-\gamma$
  - Determine the energy dep. part $g(E_\gamma)$ of C_γ using $e^+e^- \to \mu^+\mu^-\gamma$ for the high E_γ range and $\pi^0 \to \gamma\gamma$ data for the low E_γ range



Energy Calibration at large Eγ

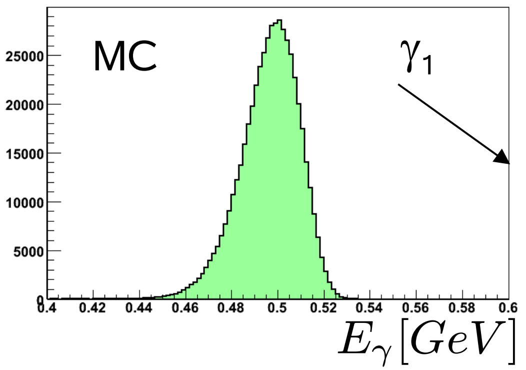
- The calibration scheme for γ's from $e^+e^- \to \mu^+\mu^-\gamma$ $(400\,MeV < E_\gamma < 6\,GeV)$
  - Predict the γ energy by a kinematic fit
    - constrain event to vertex and beam spot
    - apply mass cronstraint to μ and γ
  - Measurement of the γ calibration function
    - Measure the mean as peak position of a fit to an extended Novosibirsk function
    - Determine $h(\theta_\gamma)$ in 3 Eγ bins considering data/MC ratios of the mean
    - Apply $h(\theta_\gamma)$ and determine $g(E_\gamma)$ using data/ MC ratios
  - Non gaussian line shape of the γ response causes systematic shifts

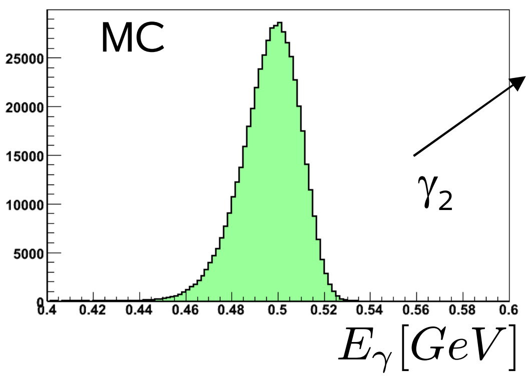


$$\Longrightarrow \quad \left(\frac{E_{raw}}{E_{fit}}\right)_{MC} \Big/ \left(\frac{E_{raw}}{E_{fit}}\right)_{data}$$

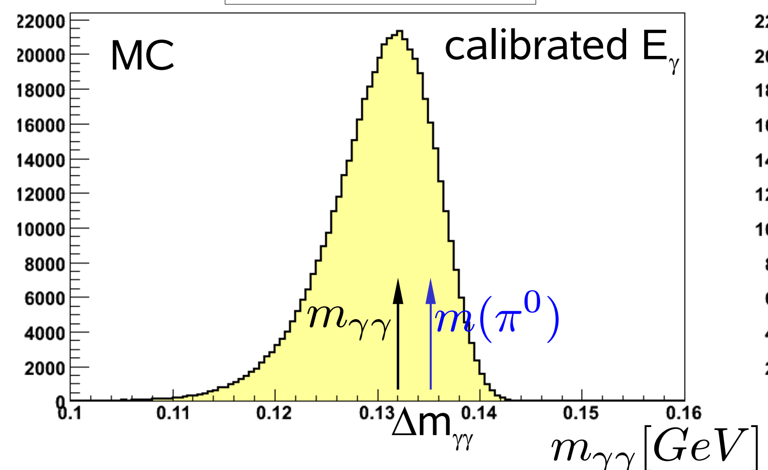
Energy Calibration at low Eγ (1)

- The π^0 calibration scheme $(70\,MeV < E_\gamma < 2\,GeV)$
  - ➢ Measurement of the γ energy calibration function in π^0 data

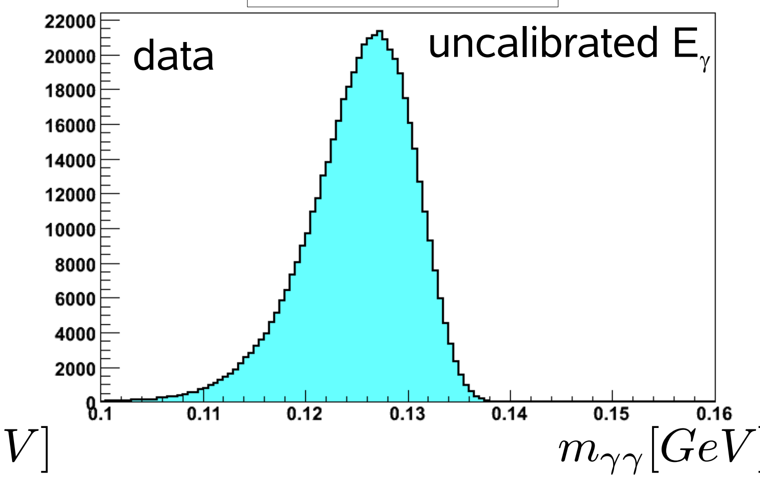




symmetric π^0



symmetric π^0



Normalize

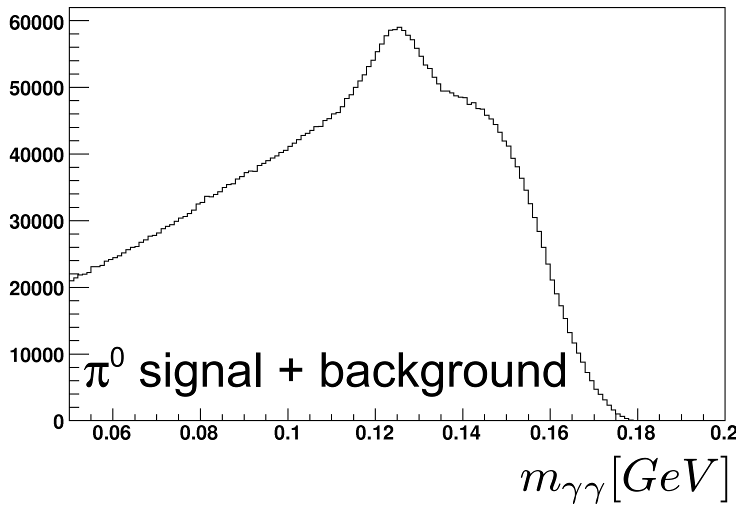
γ energy calibration

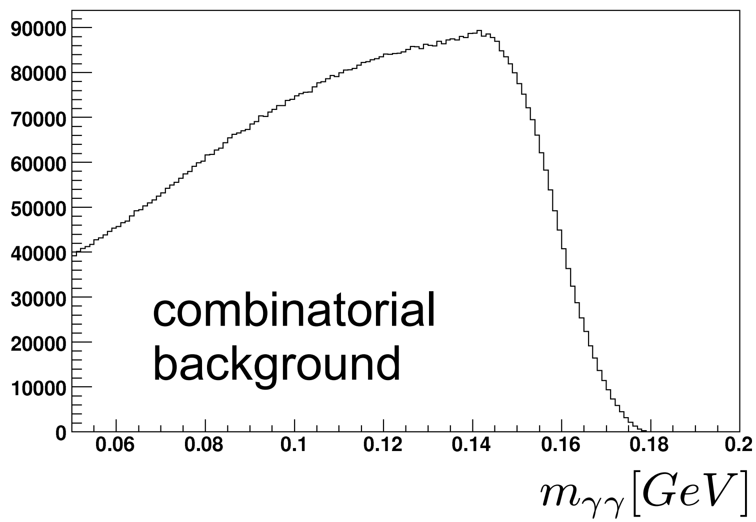
$$\Delta m_{\gamma\gamma} = m(\pi^0) - m_{\gamma\gamma} = f(\sigma_E, \tau_E, \sigma_{pos})$$

$$g(E_\gamma)$$

Energy Calibration at low Eγ (2)

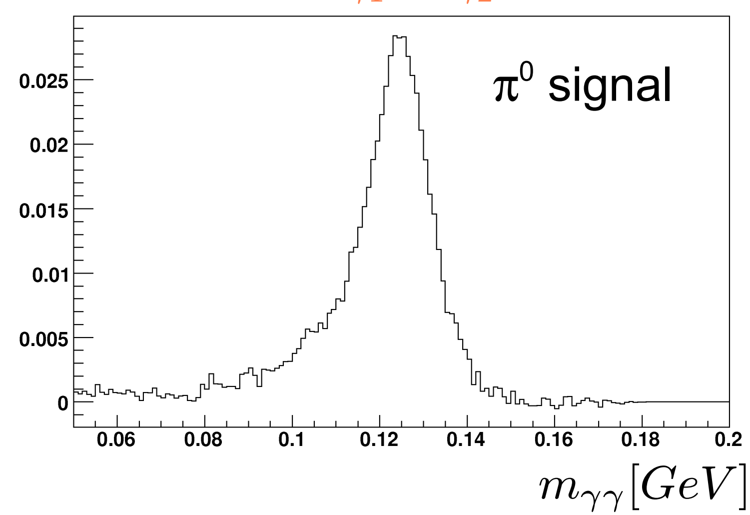
- π^0 signal processing:





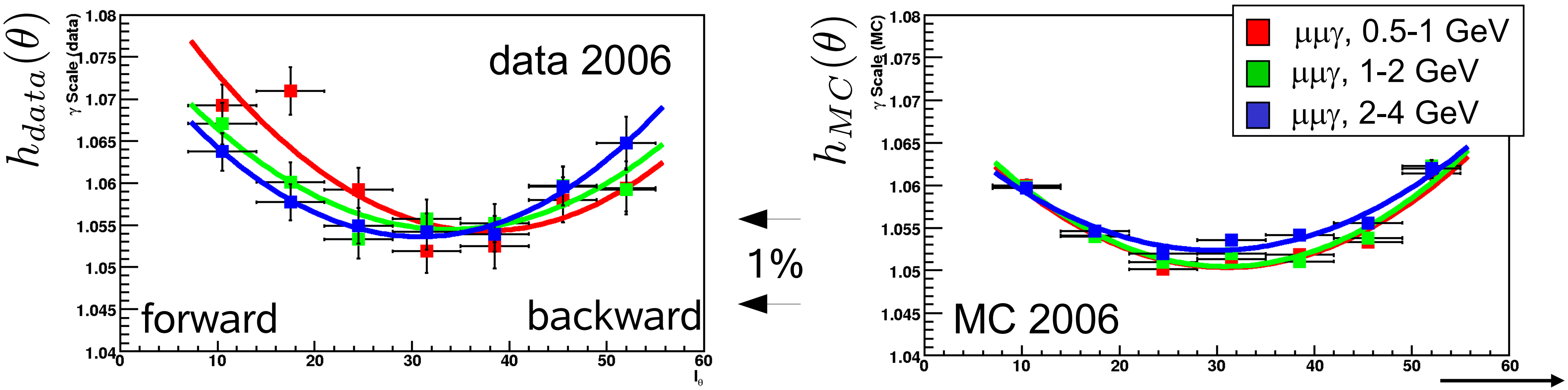
- Determine combinatorial background combining γ 's from different events
- Measure the mean as peak position of a fit to an extended Novosibirsk function
- Signal after background subtraction:

$$70\,MeV < E_{\gamma_1}, E_{\gamma_2} < 90\,MeV$$



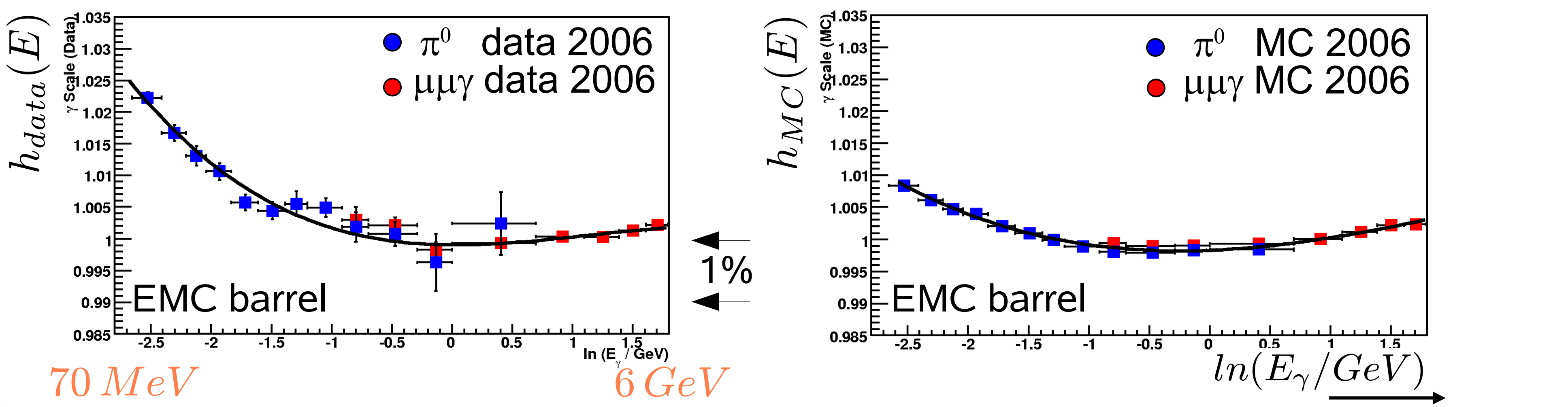
Calibration Functions

- Calibration parametrization – θ dependence in $e^+e^- \rightarrow \mu^+\mu^-\gamma$



θ crystal index

- Calibration parametrization – E dep. π^0 's and γ^0 's from $e^+e^- \rightarrow q\,\bar{q}\;,\;\mu^+\mu^-$

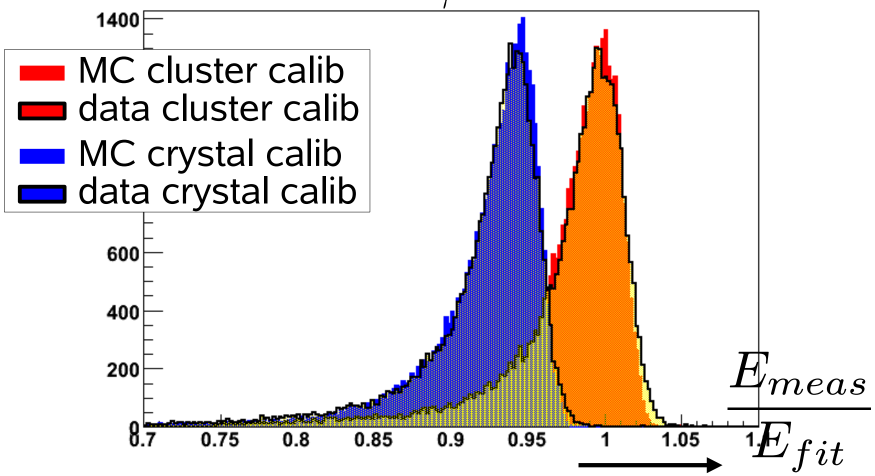


Cluster Energy Calibration Results

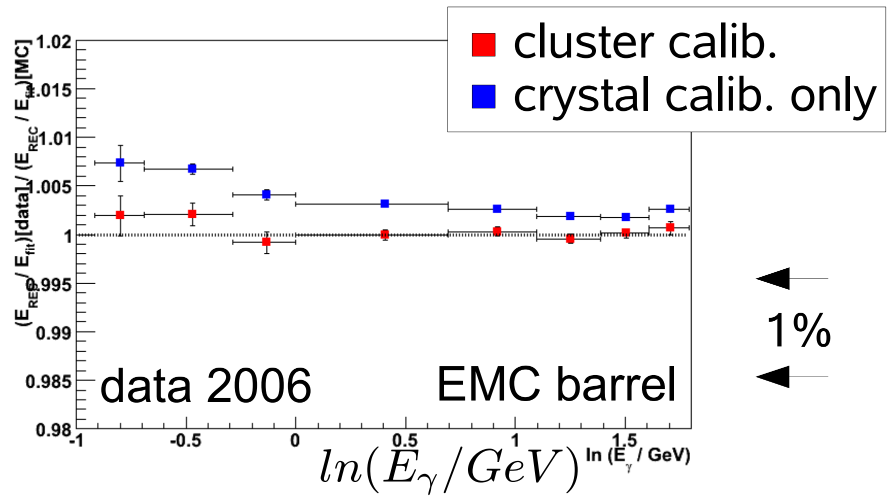
- Results for the process $e^+e^- \rightarrow \mu^+\mu^-\gamma$ $400\,MeV < E_\gamma < 6\,GeV$

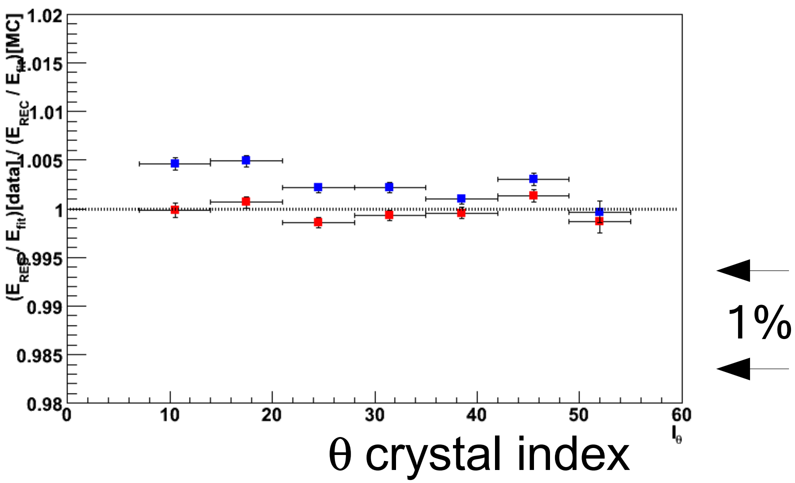
  γ signals:

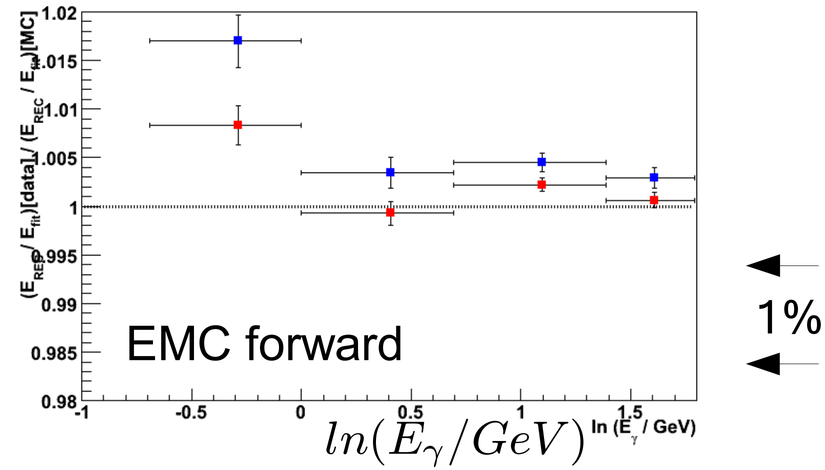
$5\,GeV < E_\gamma < 6\,GeV$



$$\left\langle \frac{E_{calib}}{E_{fit}} \right\rangle_{data} \Big/ \left\langle \frac{E_{calib}}{E_{fit}} \right\rangle_{MC}$$



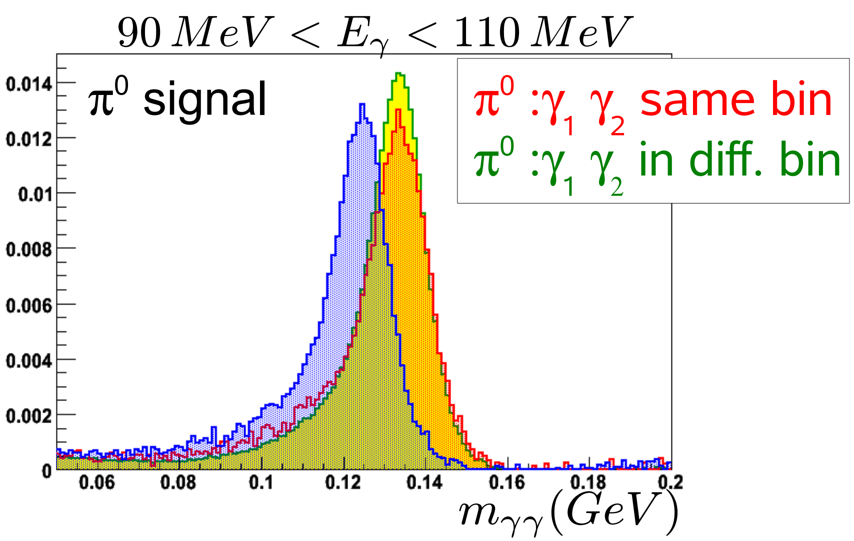


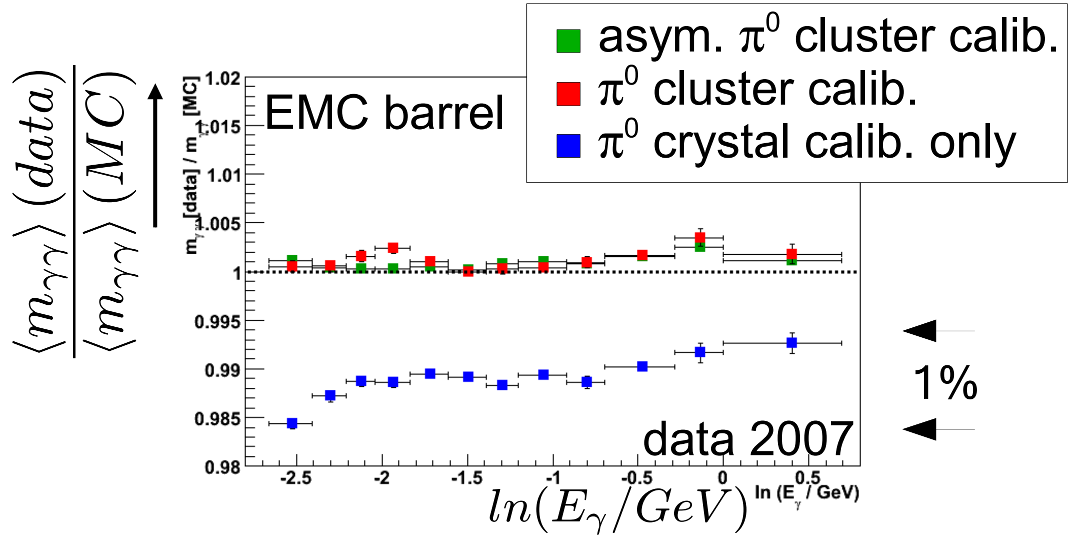


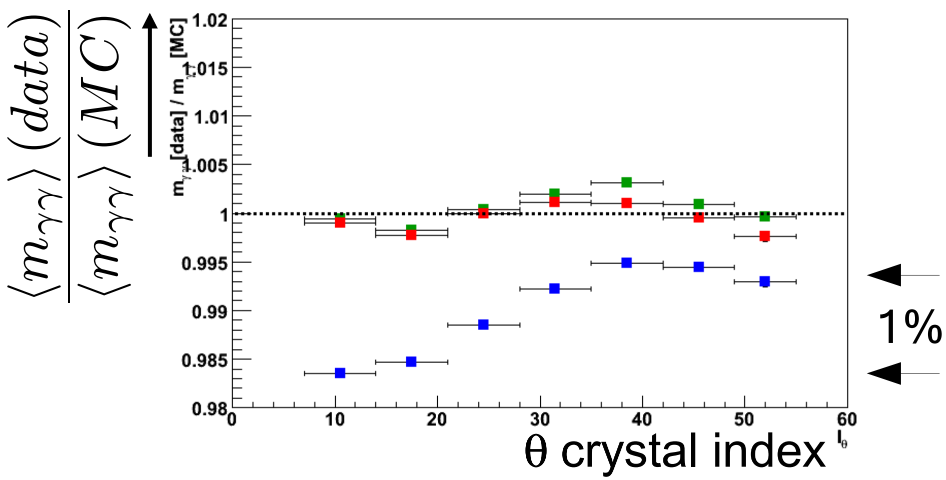
Cluster Energy Calibration Results

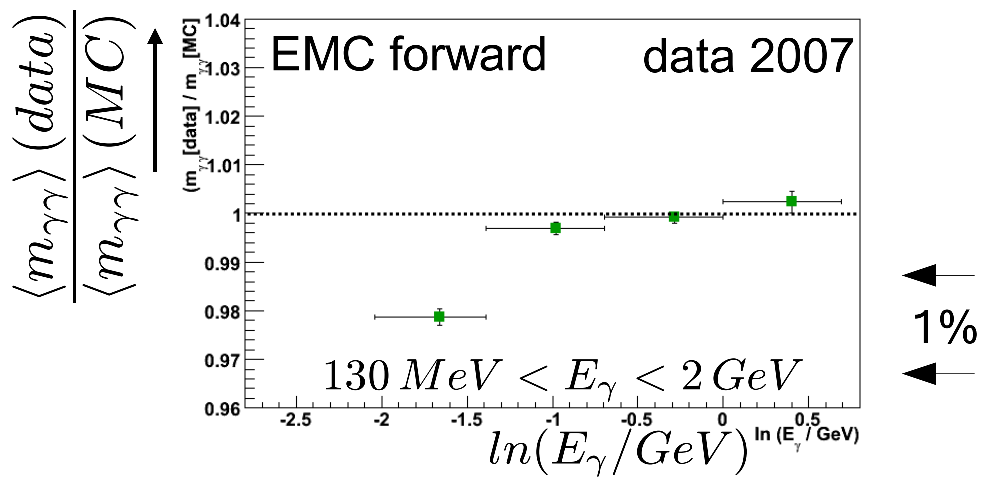
- Results for π^0 from processes $e^+e^- \rightarrow q\,\bar{q}$ $\quad 70\,MeV < E_\gamma < 2\,GeV$

  Background subtracted π^0 signals:









Calibration Validation – Low Eγ

- $\Sigma^0 \rightarrow \Lambda^0 \gamma \rightarrow p\, \pi^- \gamma$ an independent γ energy scale measurement

  - Photon energy range: $50\, MeV < E_\gamma < 400\, MeV$

  - Determine $E_\gamma^{calc} = \dfrac{M_\Sigma^2 - M_\Lambda^2}{2(E_\Lambda - p_\Lambda cos\,\theta_{\Lambda\gamma})}$

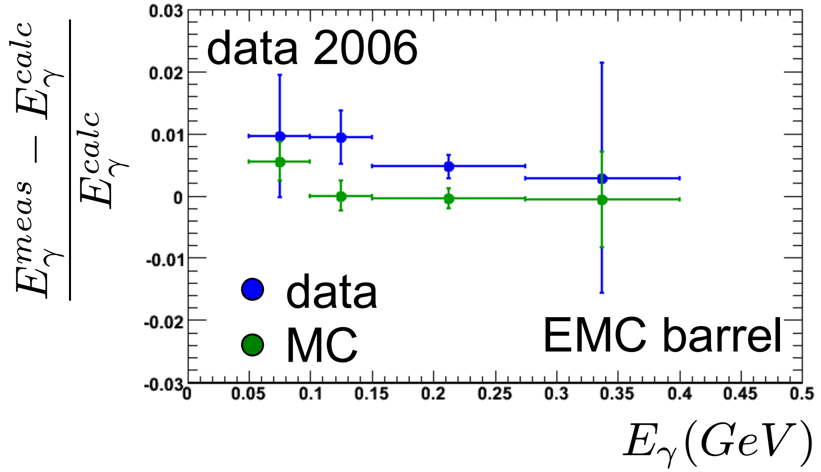
    $E_\gamma^{calc} = f(p_p, p_\pi, m_p, m_\pi, E_\gamma, \theta_\gamma)$

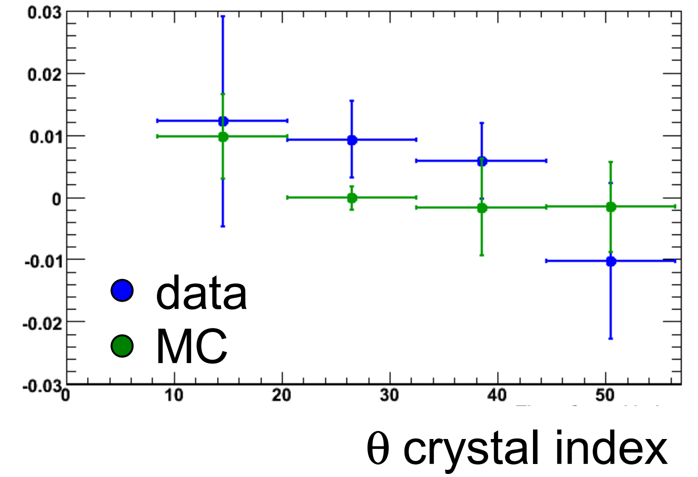
    tracking, particle id   calorimeter

  - Measure the peak position of $\dfrac{E_\gamma^{meas} - E_\gamma^{calc}}{E_\gamma^{calc}}$

    in projections of E_γ, θ_γ

  - Absolute γ energy scale is correct within systematic errors and the data is well described by MC





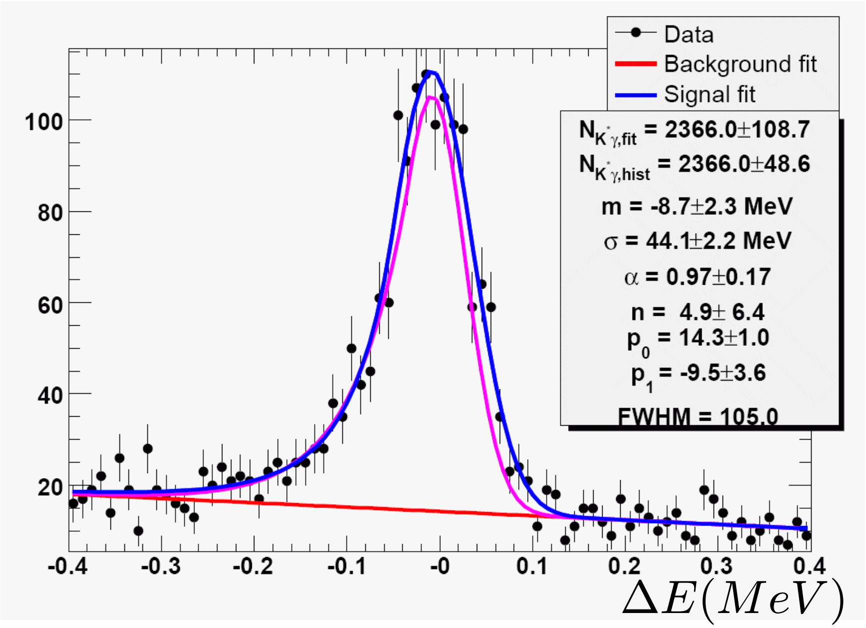
Calibration Validation – High Eγ

- $B^0 \rightarrow K^{*0}\gamma$ an independent γ energy scale measurement
  - Consider the process $B^0 \rightarrow K^{*0}\gamma \rightarrow K^+\pi^-\gamma$ and measure ΔE

$$\Delta E = E^{*B^0}_{rec} - E^*_{beam} = f(p_K, p_\pi, m_K, m_\pi, E_\gamma)$$

tracking, particle id calorimeter

  - Photon energy range: $1.5\,GeV < E_\gamma < 3.5\,GeV$



$$\Delta E_{data} = -8.7 \pm 2.3\ MeV$$
$$\Delta E_{MC} = -8.5 \pm 0.2\ MeV$$

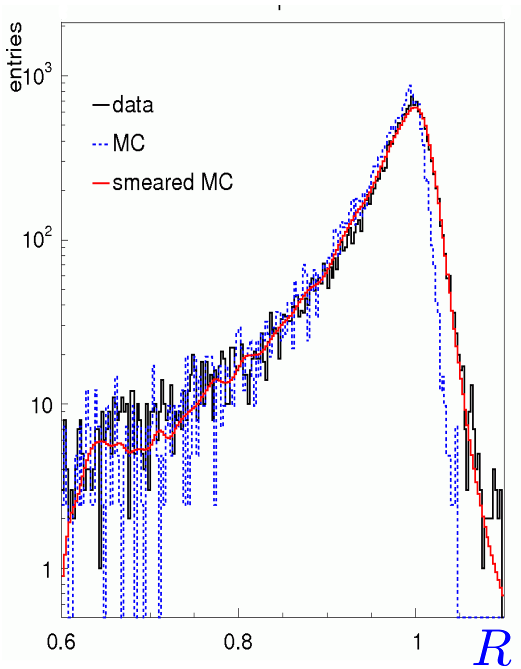
MC describes the data

- Systematic deviation of the photon energy scale

$$\delta E_{data} = 0.35 \pm 0.09\ \%$$

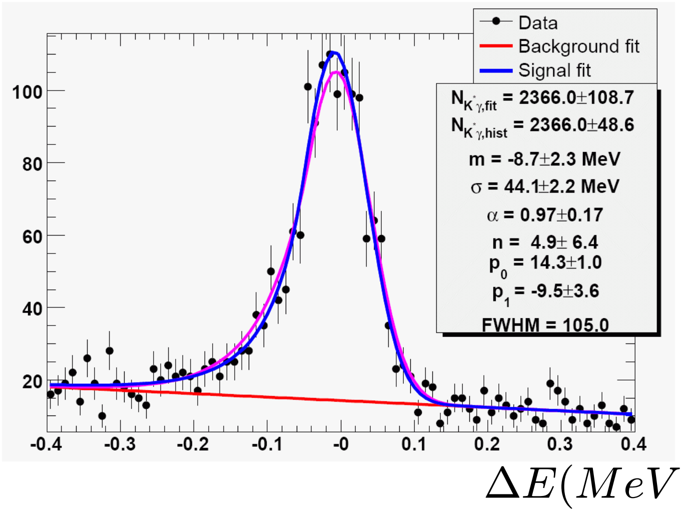
Energy Resolution Smearing

- **Motivation**
  - Line shape of the γ response is not described by MC
  - Difficult to model selection criteria and efficiencies of different physics processes



- **Approach**
  - Add another term to the simulated γ response which reflects the difference of the measurement and MC
  - Use the normalized response $R = E^{\gamma}_{meas}/E^{\gamma}_{fit}$ of photons from $e^+e^- \to \mu^+\mu^-\gamma$

- **Results**
  - $B^0 \to K^{*0}\gamma$: after smearing ΔE_{data} matches ΔE_{MC}

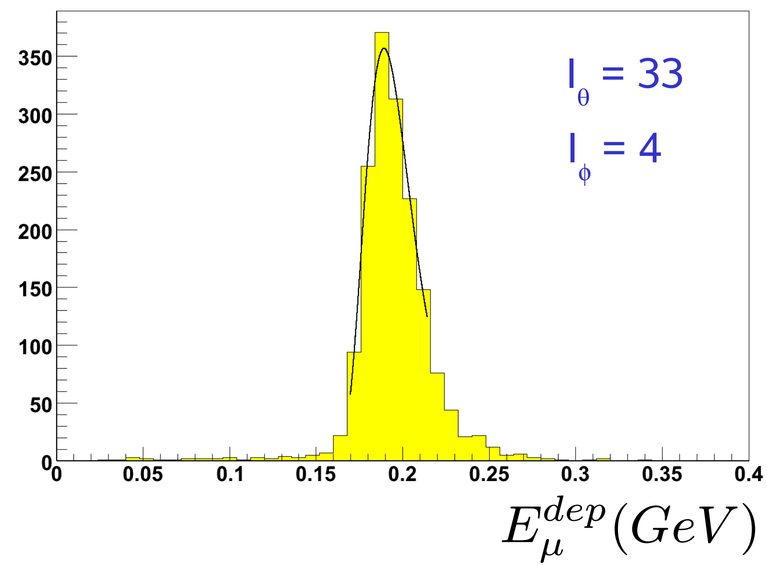


EMC Monitoring using Muon Signals

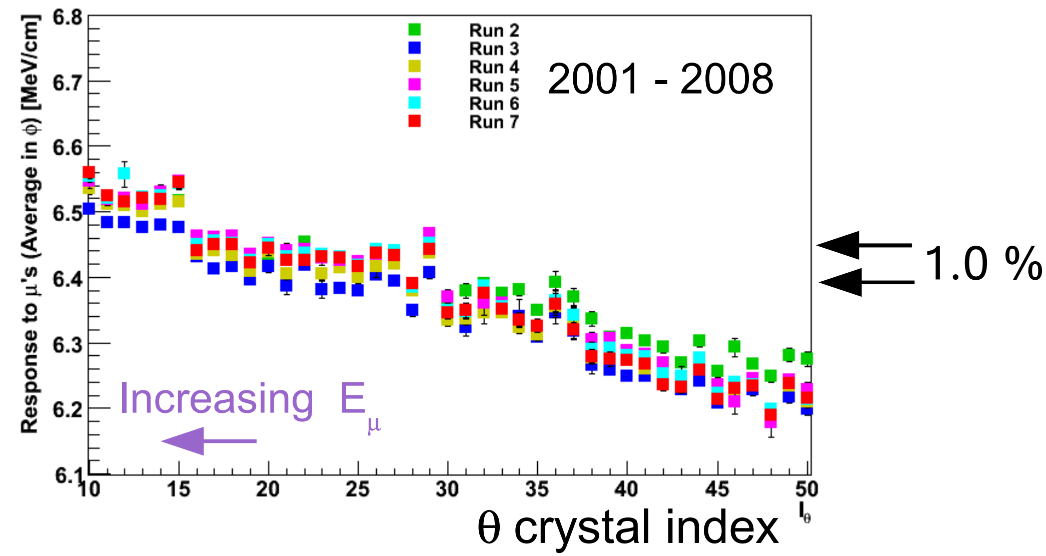
- μ response in the EMC from $e^+e^- \rightarrow \mu^+\mu^-$

The muon response is a measure for the time stability of the crystal calibration

➢ μ response – one crystal

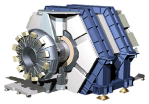


➢ μ response - crystal average in ϕ



Slope arises from the relativistic rise of the dE/dx

➢ Calibration using μ signals is not possible due to the non uniform light yield over the crystal length

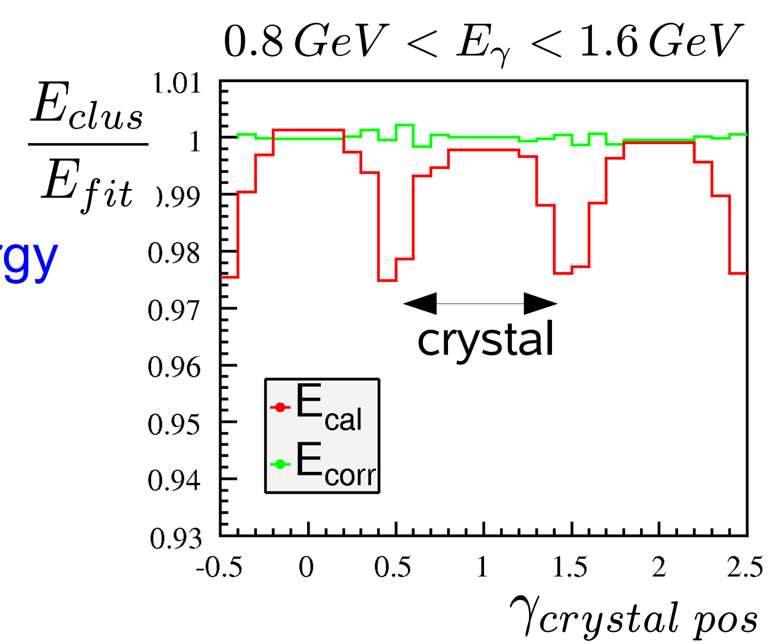


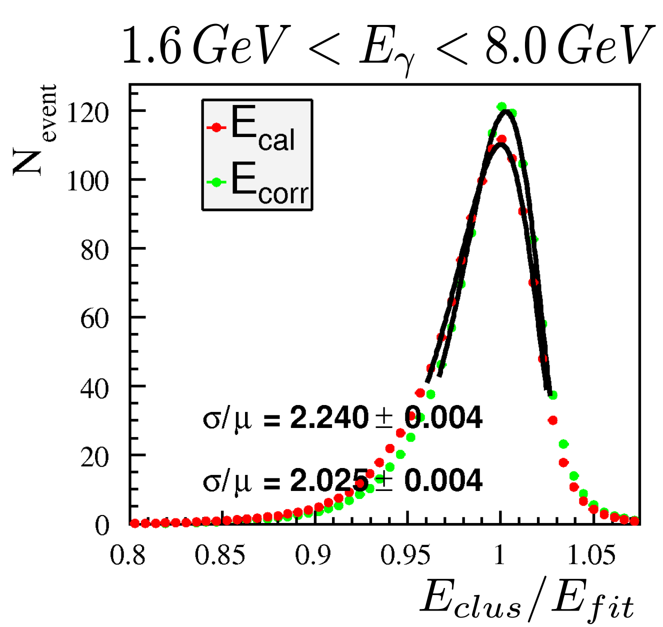
Lateral non Uniformity Correction

- The calibration scheme for γ 's from $e^+e^- \rightarrow \mu^+\mu^-\gamma$

  - Non uniform response across the crystal surface due to dead material between the crystals

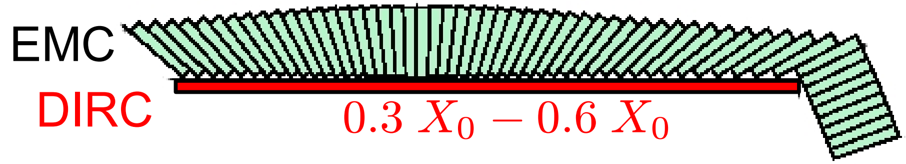
  - Determine a 2d calibration function in 5 energy bins (0.4 – 8.0 GeV)



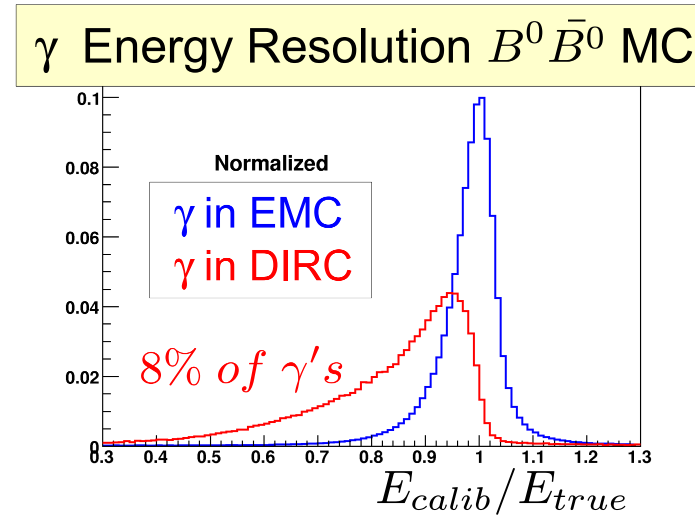


  - Applying the calibration function
    - response over the crystal surface is flat
    - resolution improves by 10 %

EMC Cluster and DIRC Association



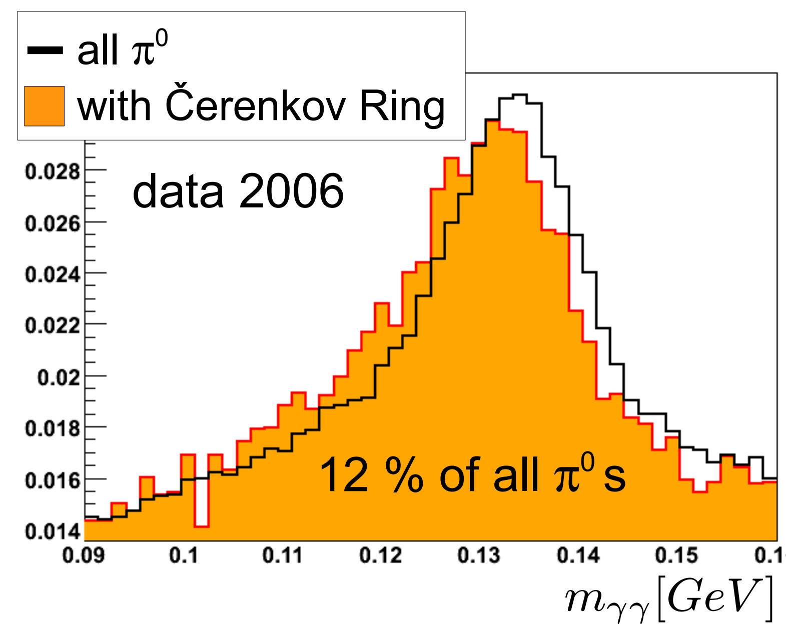
- **Motivation**
  - Energy loss due to dead material in front of the EMC contributes significantly to the line shape and resolution of the response to γ 's

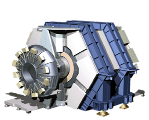


- **Approach**
  - Identify showers starting in front of the EMC by association of Čerenkov rings and EMC clusters
  - Purpose
    - Selection of control samples
    - Energy correction
- **Selection results**

Enhance events with early γ showers

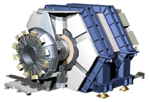
	associated with DIRC $B^0\bar{B}^0$	associated with DIRC $\mu^+\mu^-\gamma$
$N^{DIRC}_{true\ shower}/N^{rec}$	37%	60%





Summary

- The cluster calibration scheme of the *BABAR* CsI calorimeter covering an energy range from 70 MeV to 6 GeV was presented and deviations of the absolute energy scale not larger then 0.35 % at high energies were found.
- The decription of the data by the MC simulation is very good as a result of the calibration.
- Sub crystal level calibration improves the homogeneity of the response and the calorimeter resolution.
- The association of the particle indentification system DIRC and the calorimeter allows the selection of a subset of γ's with a shower start in the calorimeter.

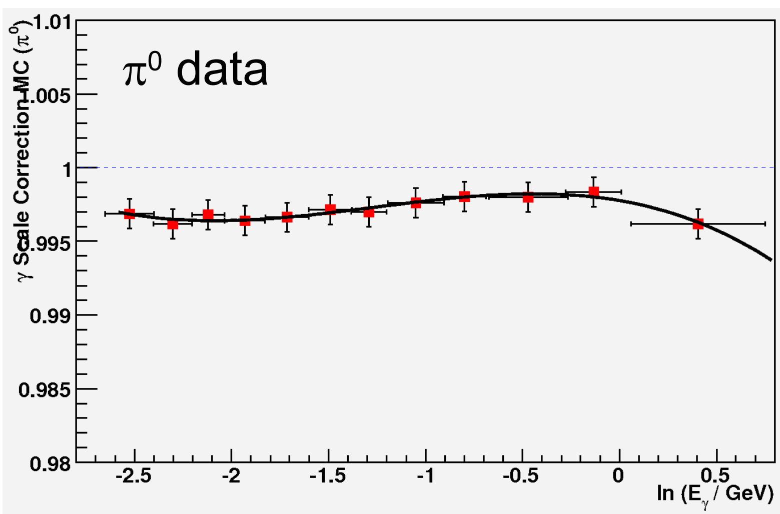


Systematic Errors

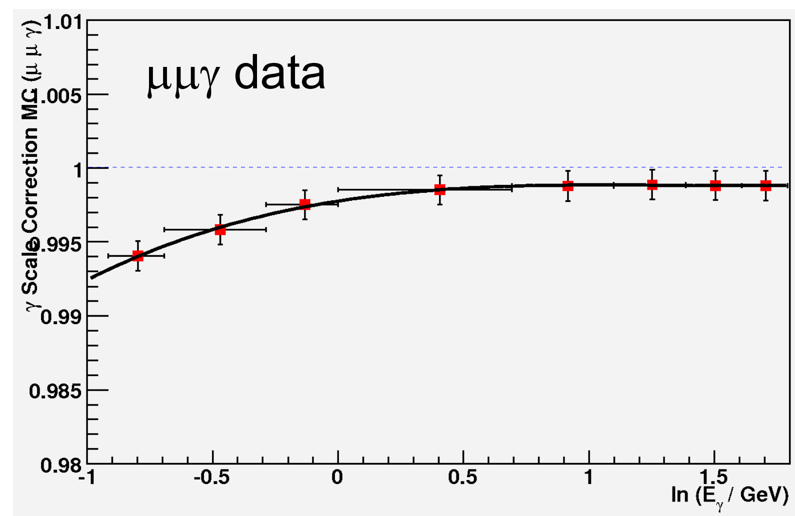
- Calibration correction function / systematic errors
  - The difference in the data and MC response causes systematic shifts of $\Delta m_{\gamma\gamma}$ and $\langle E_{raw}/E_{fit}\rangle$
    - π^0 data: parametrize the γ response by a Novosibirsk function and determine

$$\Delta m_{\gamma\gamma} = m_{\gamma\gamma}^{true} - m_{\gamma\gamma}^{meas} = f(\sigma_{Nov}, \tau_{Nov})$$

    - $\mu\mu\gamma$ data: parametrize the γ response and change the resolution of E_{fit}

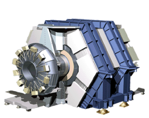


correction factor



$ln(E_\gamma/GeV)$

  - Treated as systematic error rather as a correction



EMC - Muon Signals

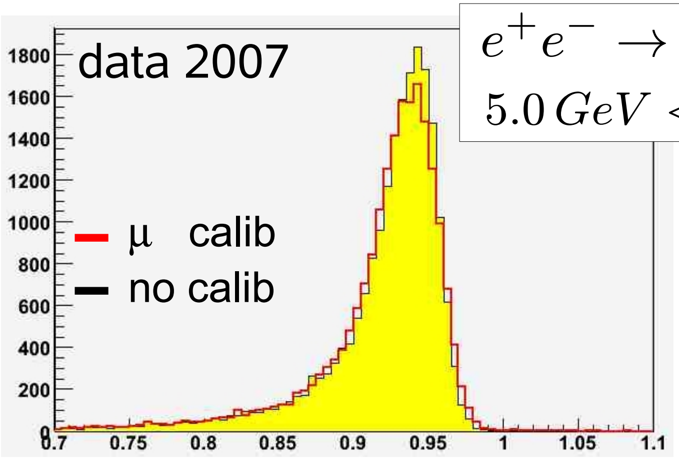
- μ response in the EMC from $e^+e^- \to \mu^+\mu^-$
  - Calibration with μ signals ?

    Determine calibration factors for each crystal using muon signals

    Response changes due to non homogeneous light yield.

    No improvement in resolution

$e^+e^- \to \mu^+\mu^-\gamma$:
$5.0\,GeV < E_\gamma < 6.0\,GeV$



$\frac{E_{clus}}{E_{\mu\mu\gamma\ fit}}$