The Electromagnetic Calorimeter of the Babar Detector

Caltech

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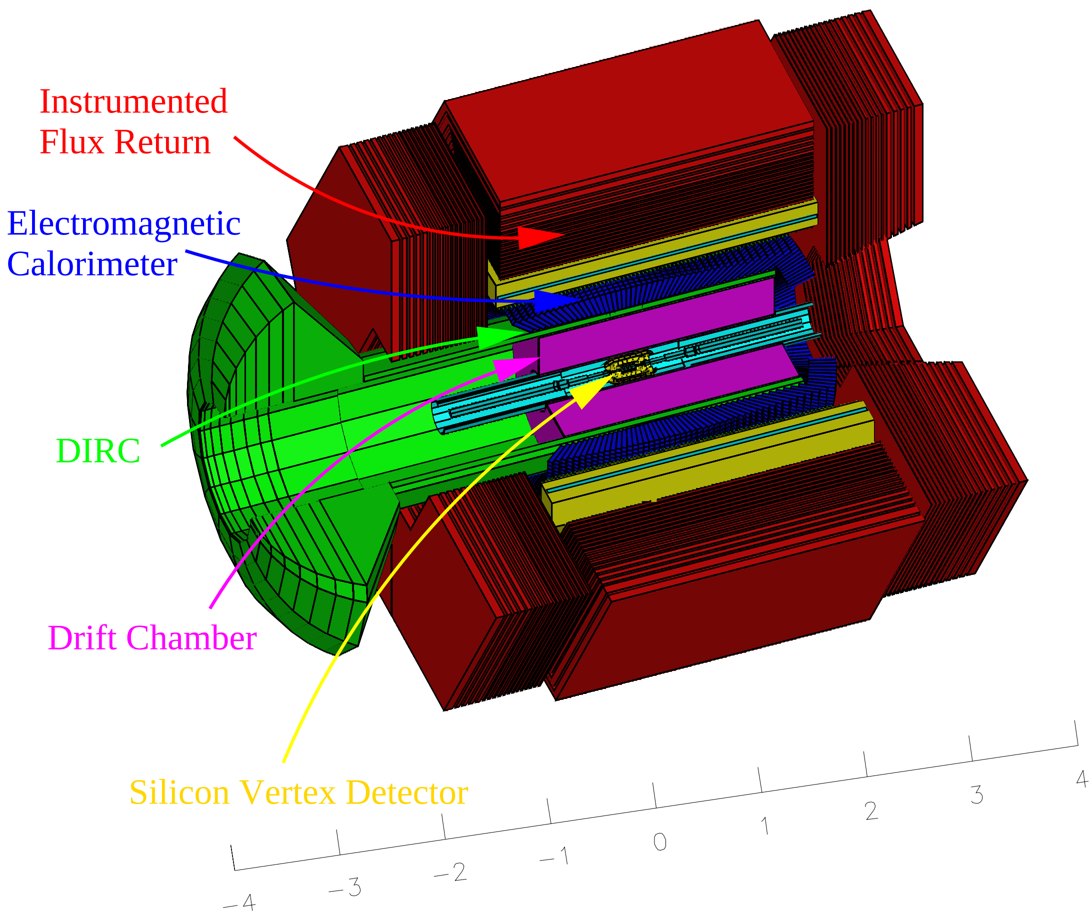
for the EMC Group and the Babar Collaboration

- ▷ The Babar Detector
- ▷ The Babar Calorimeter
- ▷ Calibration
- ▷ Performance

The B-factory at SLAC

- Asymmetric B factory:
  - e^--beam at 9 GeV, e^+-beam at 3.1 GeV
  - $e^+e^- \longrightarrow \Upsilon(4s) \longrightarrow B\bar{B}$
  - Peak luminosity presently at $4.5 \cdot 10^{33}$ cm^{-2}s^{-1}
  - Data recorded until now: 75 fb^{-1}

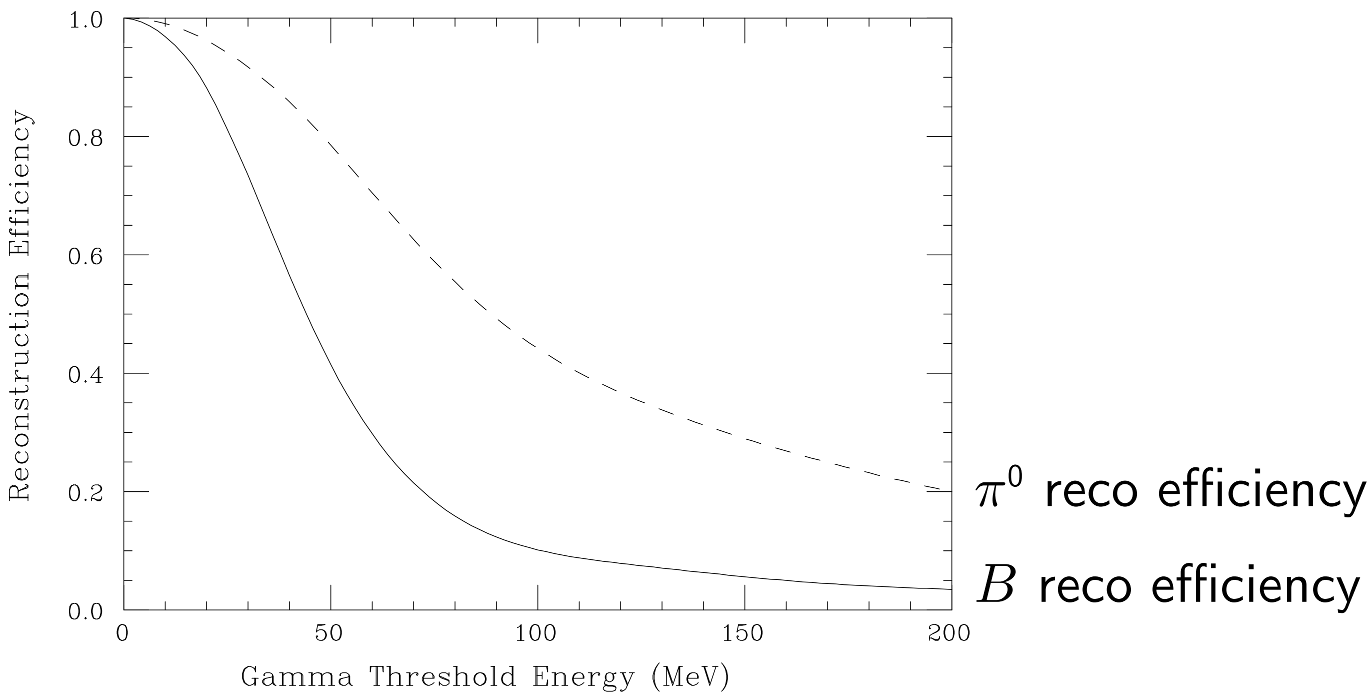
The BaBar Experiment



- Measurement of $\mathcal{CP}$ violation in B decays
- The calorimeter's main task is the reconstruction of:
  - Electrons
    - "Golden channel" for sin(2β):$B^0 \rightarrow J/\Psi K_s, J/\psi \rightarrow e^+e^-$
    - Flavor tagging
  - π^0s - determination of sin(2α) : $B^0 \rightarrow \pi^0\pi^0$
  - Photons

Calorimetry goals

- High efficiency for photons is needed for B reconstruction:

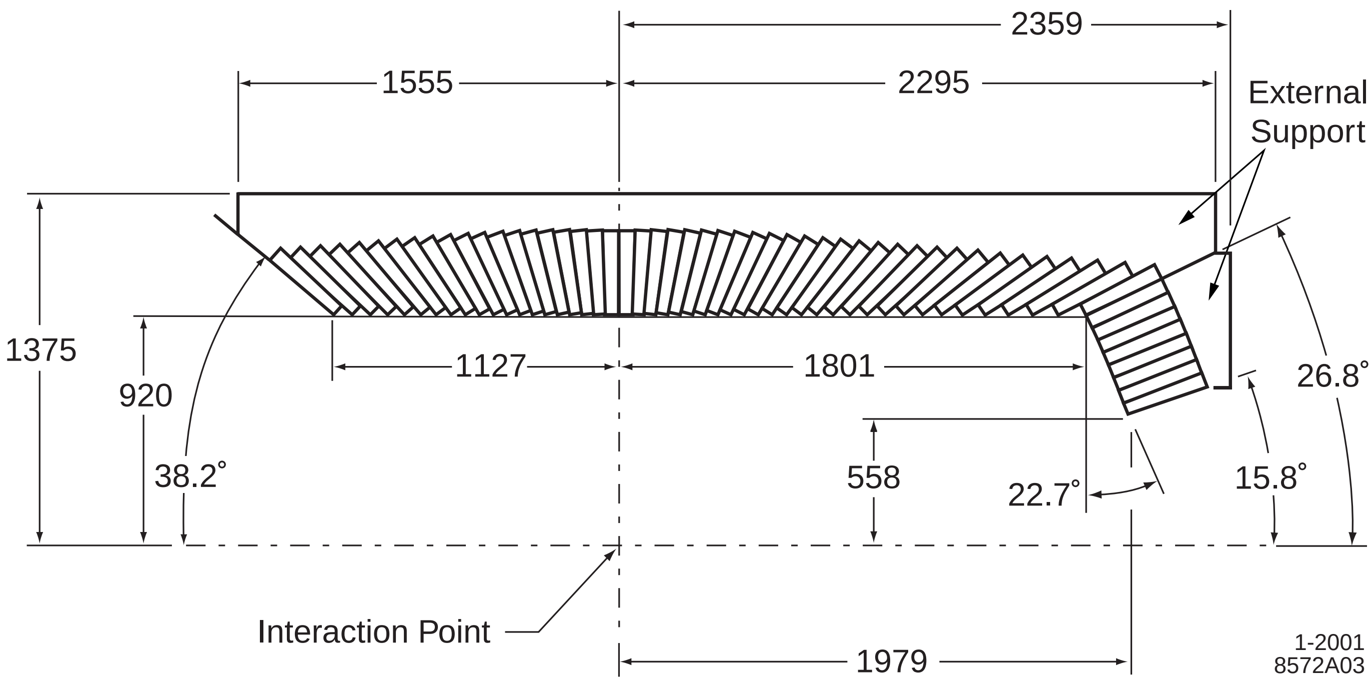


- High lightyield is needed
- Description of the resolution:

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt[4]{E(GeV)}} \oplus b$$

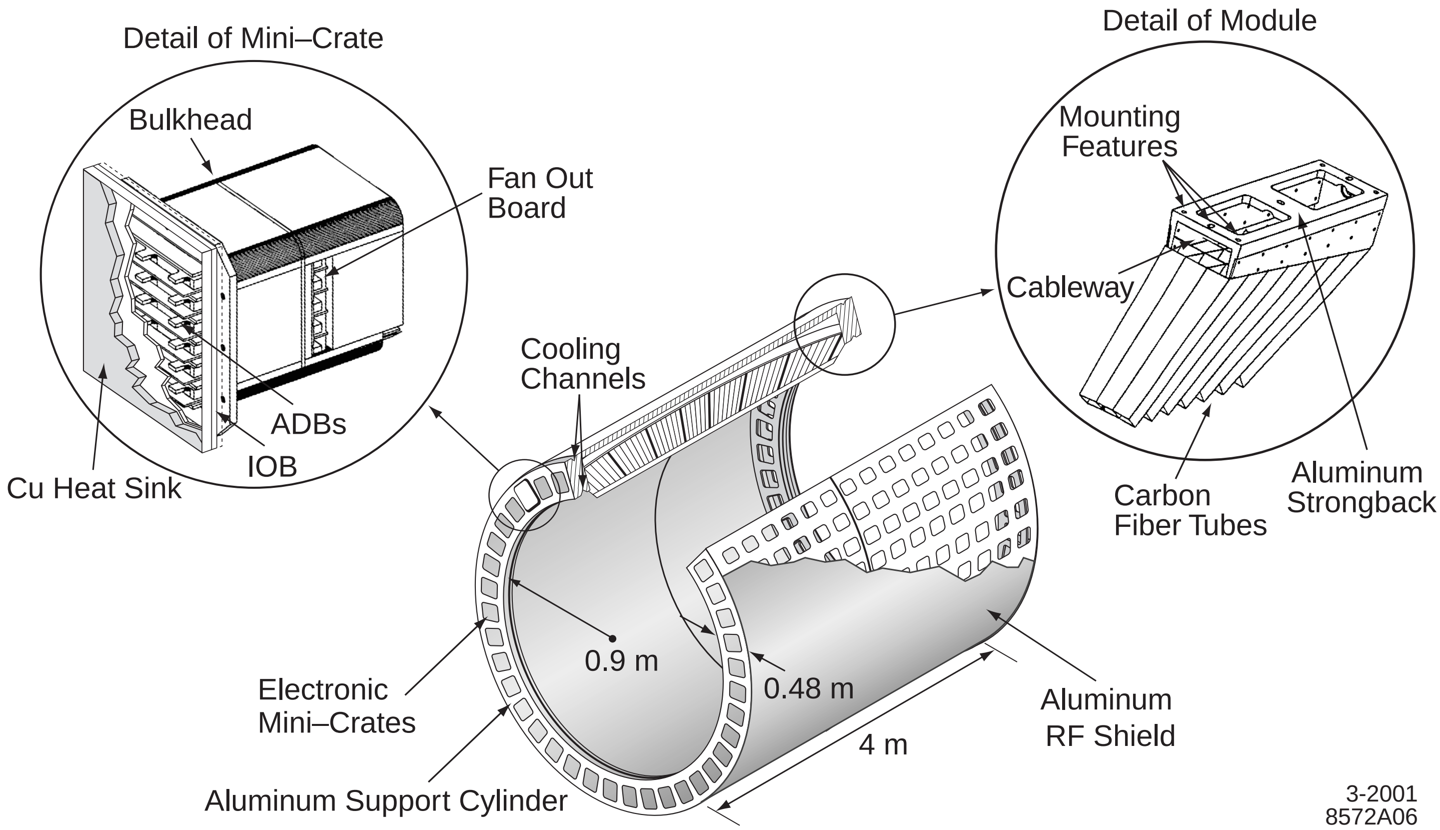
- The constant term contains:
  - Calibration error
  - Crystal nonuniformity
  - Leakage

Calorimeter Overview



- 6580 CsI(Tl) crystals
- Barrel: 48 rings in θ, 120 crystals per ring
- Forward Endcap: 8 rings in θ, 80/100/120 crystals per ring
- Angular coverage: 126° in θ, 360° in ϕ
- Crystals are non-projective in θ by 14 mrad (45 mrad in the barrel/endcap transition region)
- Gap of ca. 2 mm between barrel and endcap, fully covered by non-projectivity

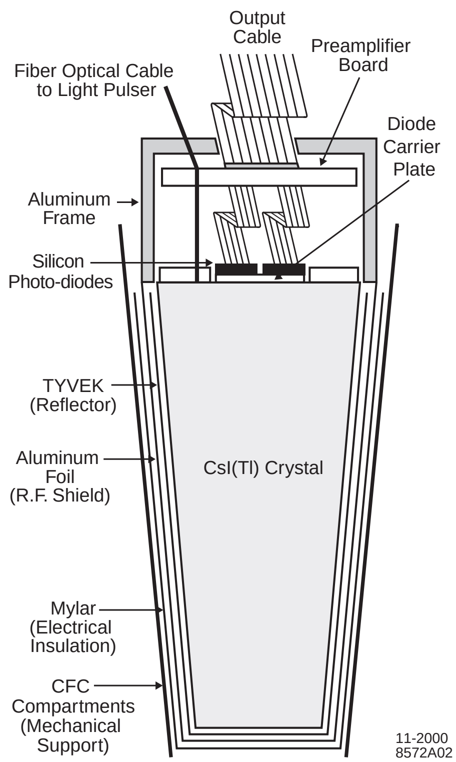
Calorimeter Support Structure



- Barrel
  - 280 carbon fiber modules
  - 7 modules along θ, 40 along ϕ
  - 7 crystals in θ, 3 in ϕ per module
- Endcap
  - 20 carbon fiber modules
  - 41 crystals per module (8 in θ, 4/5/6 in ϕ)

$\Longrightarrow$ Readout electronics: see I. Eschrich's talk

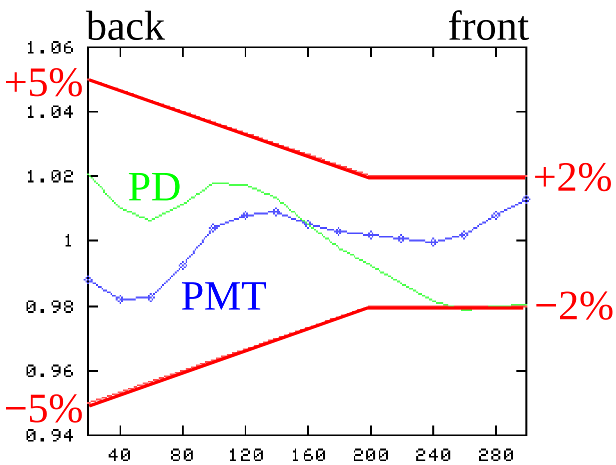
Crystal Housing

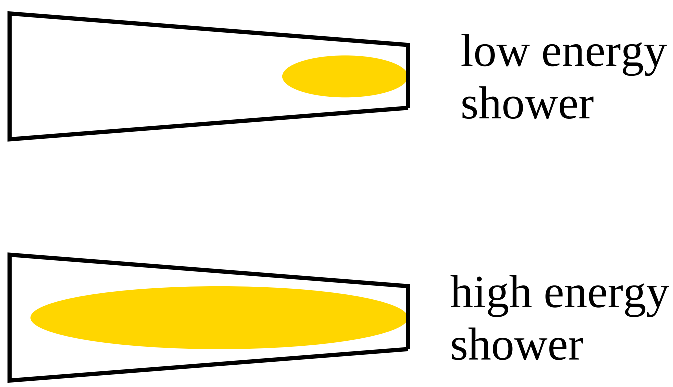


- Trapezoids: Front 4.7 x 4.7 cm^2, back 6.1 x 6.0 cm^2
- Length between 16.0 X_0 (bwd) and 17.5 X_0 (fwd)
- crystal is held in place by 300 μm of CFC
- 2 x 160 μm Tyvek wrapping for reflection and tuning
- Aluminum foil/Mylar wrapping
- Lightyield was typically 7300 photoelectrons/MeV during QC
- 2 photodiodes glued with epoxy onto the crystal via a polystyrene coupling plate - area 2 x 2 cm^2
- 2 preamps in readout box above crystal

Calibration Overview

- There are two kinds of calibrations:
- Inter crystal calibration:
  - The crystals have different lightyields
  - The crystals have different uniformities





!!! Lightyield and uniformity change with time through radiation damage

⟹ Radiation damage studies: see T. Hryn'ova's talk

- Shower corrections:
  - $E_{deposited} \neq E_{true}$
  - The deposited energy depends on the leakage that is a function of geometry and material in the detector

EMC Calibration Overview

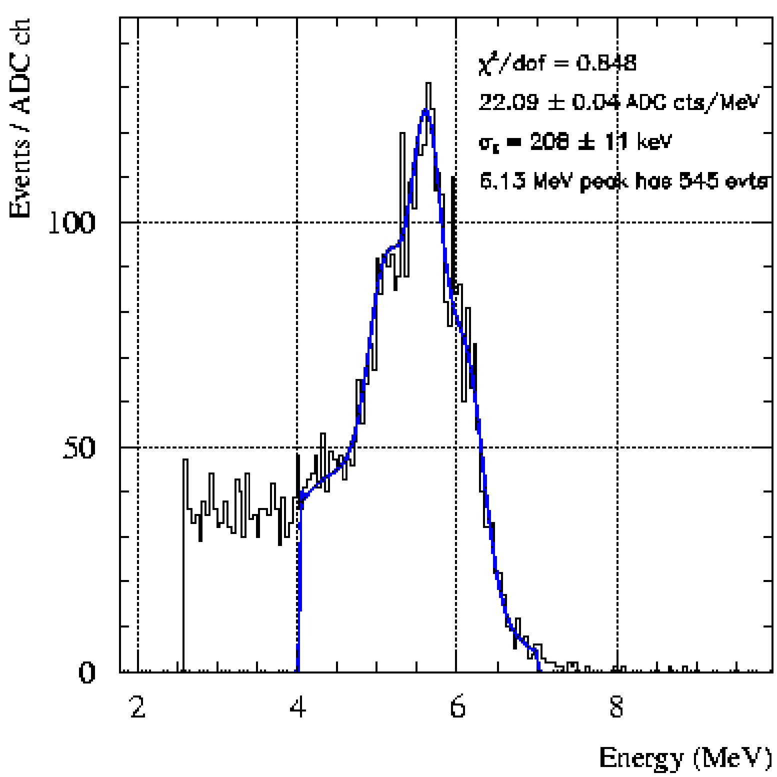
Properties of the different calibrations

	Duration	Energy scale	Single Xtal	Absolute
Source	1/2 h	0.00613 GeV	✓	✓
Bhabha	12 h	3–9 GeV	✓	✓
Rad Bhabha	1 − 2 days	0.3 − 9 GeV	−	✓
Pi 0	4 h	0.03 − 3 GeV	−	✓
Electronics	15 min	0 − 13 GeV	✓	−
Light Pulser	3 min	0 − 13 GeV	✓	−

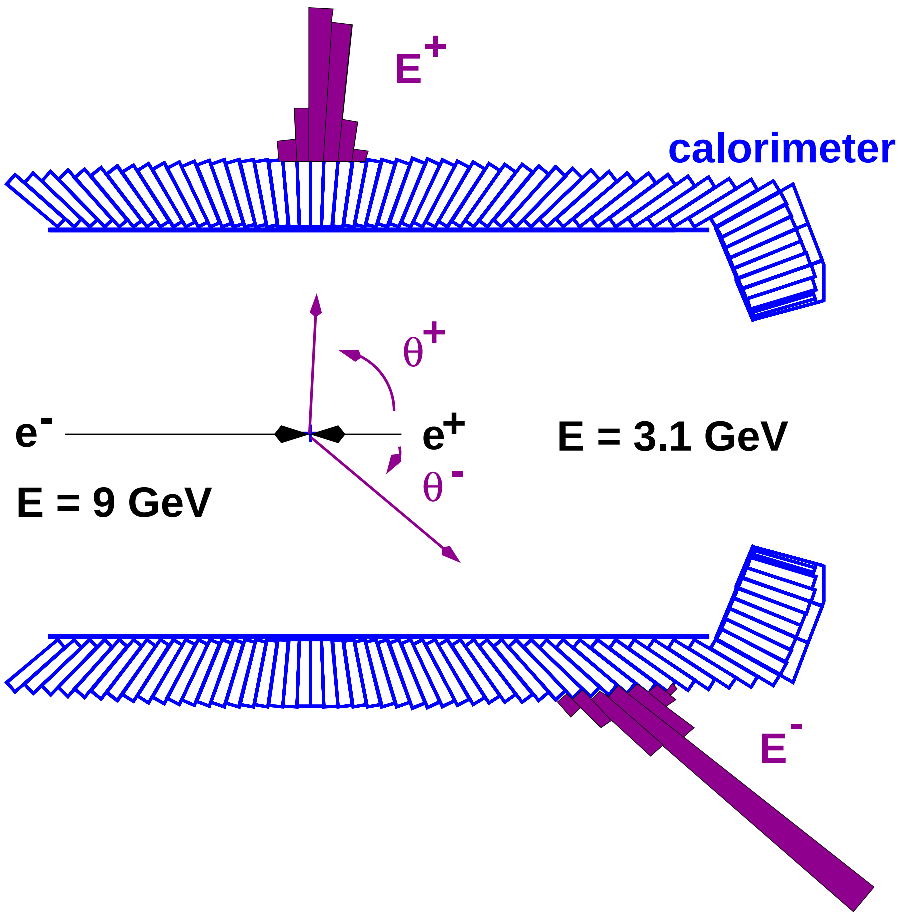
$\Longrightarrow$ The lightpulser calibration and the electronics calibration will be covered in detail in I. Eschrich's talk

Source Calibration

- Calibration uses 6.13 MeV photons from $^{16}N \rightarrow ^{16}O^* \rightarrow ^{16}O\gamma$
- ^{16}N has a lifetime of 7 seconds
- A fluid, activated by neutrons from a generator, circulates through a system of tubes in front of the crystals
- All crystals are calibrated with this method
- Resolution of the constants: 0.33 %
- Source spectrum with two escape peaks:



Bhabha Calibration I



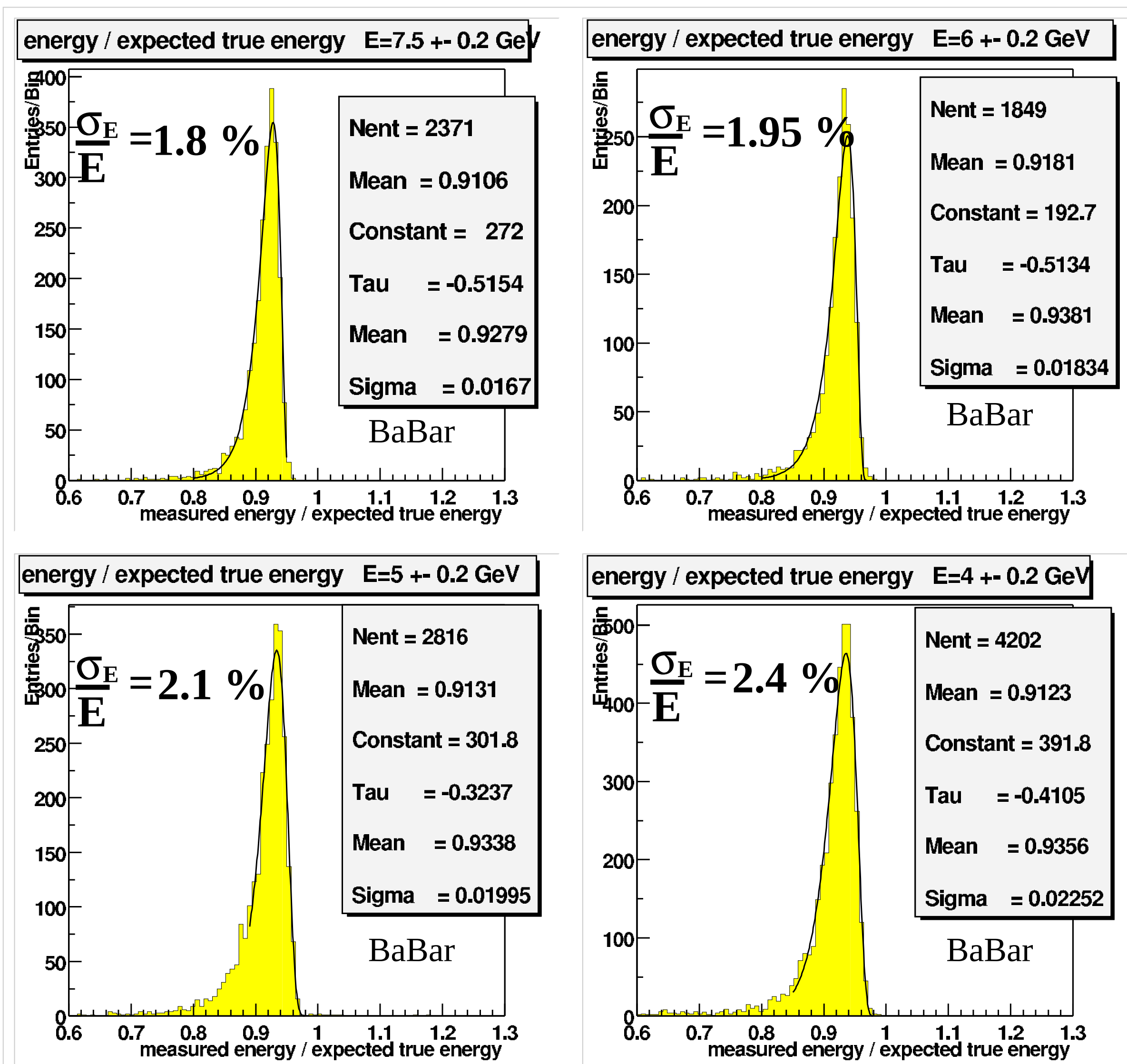
- Single crystal calibration to $E^{expected}_{deposited}$ (from MC)
- Find constants c_i so that

$$\chi^2 = \Sigma_{events} \frac{(\sum_i c_i \varepsilon_i - E^{expected}_{deposited})^2}{\sigma^2}$$

becomes minimal

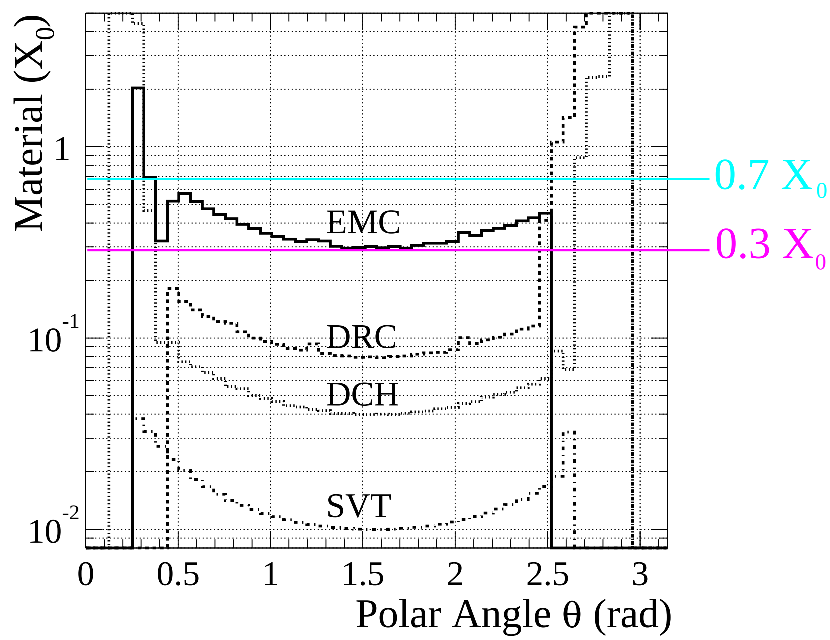
Bhabha Calibration II

- Minimization of χ^2 yields a system of linear equations with a 6580 x 6580 matrix
  $\longrightarrow$ numerical solution
- Fit with log-normal distribution



π^0 Calibration

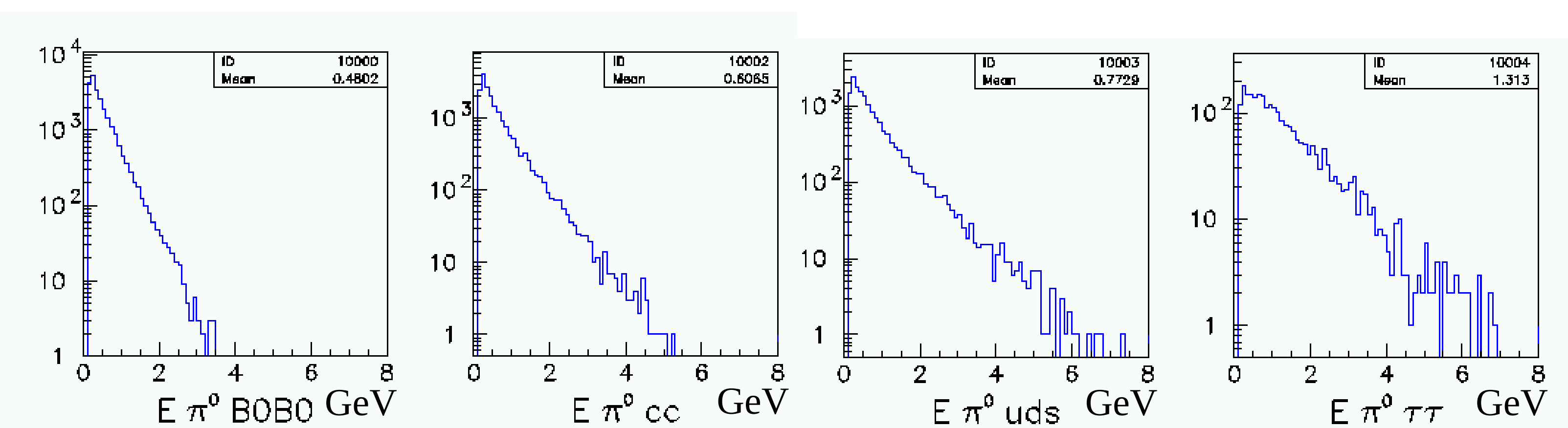
- Deposited energy $\rightarrow$ Particle's original energy
- Material in front of the calorimeter:



- Use known π^0-mass to correct the photon energies:

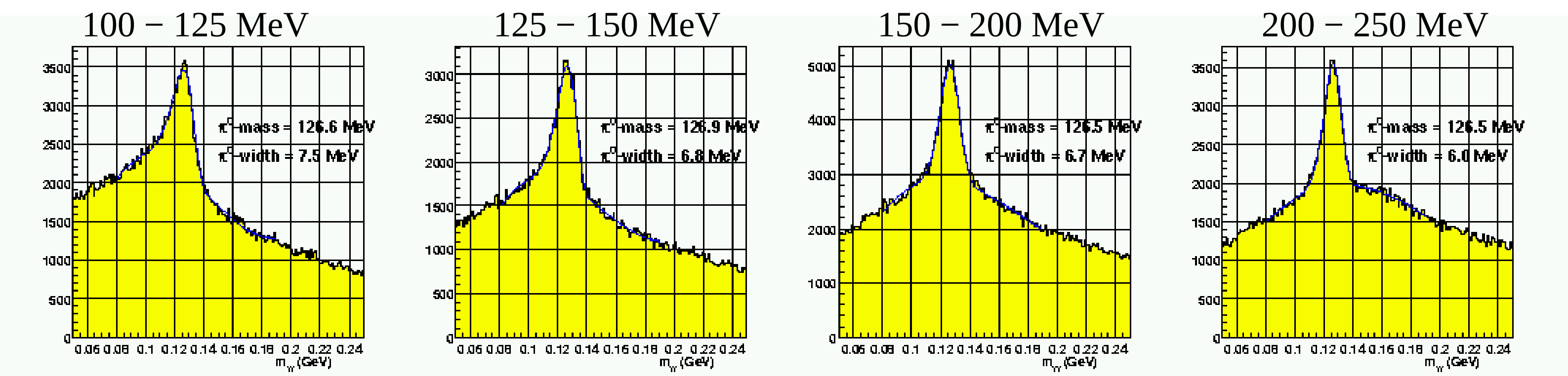
$$m_{\pi^0} = \sqrt{E_1 E_2 (1 - \cos\theta)}, \quad \theta\text{:angle between photons}$$

- π^0 spectra for different decay types:

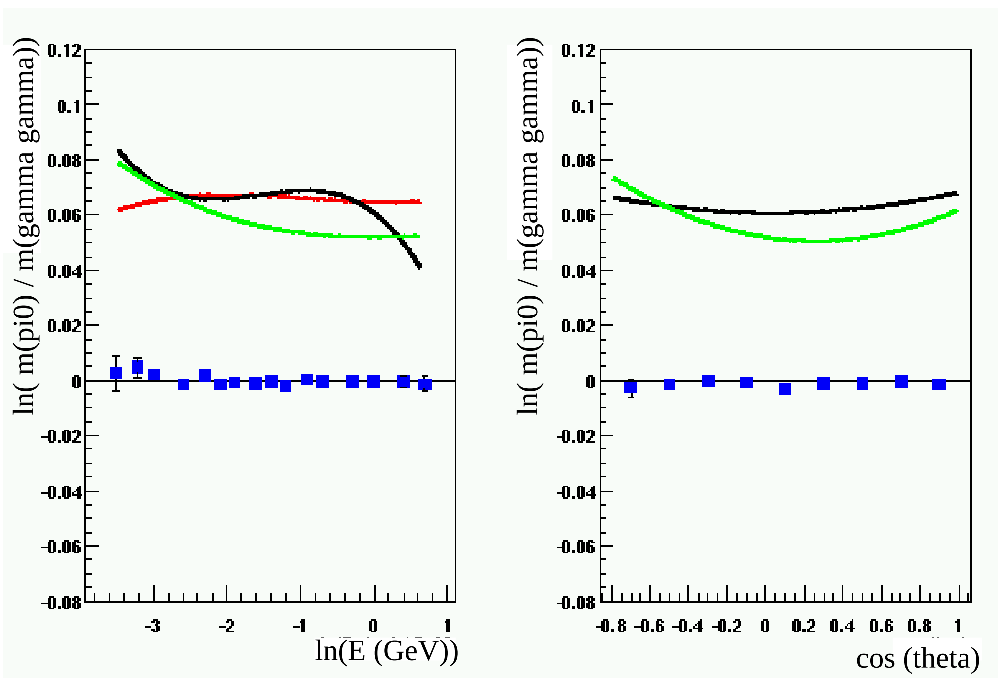


π^0 Calibration

- Make mass plots in bins of $\log_{10}(\mathrm{E})$ and $\cos(\theta)$

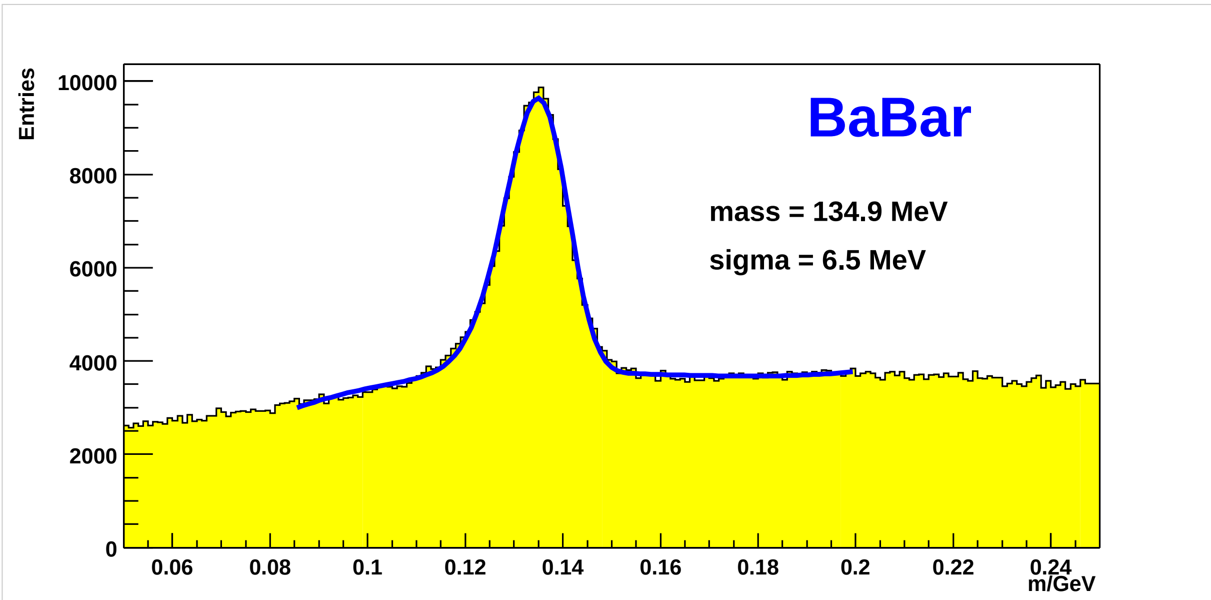


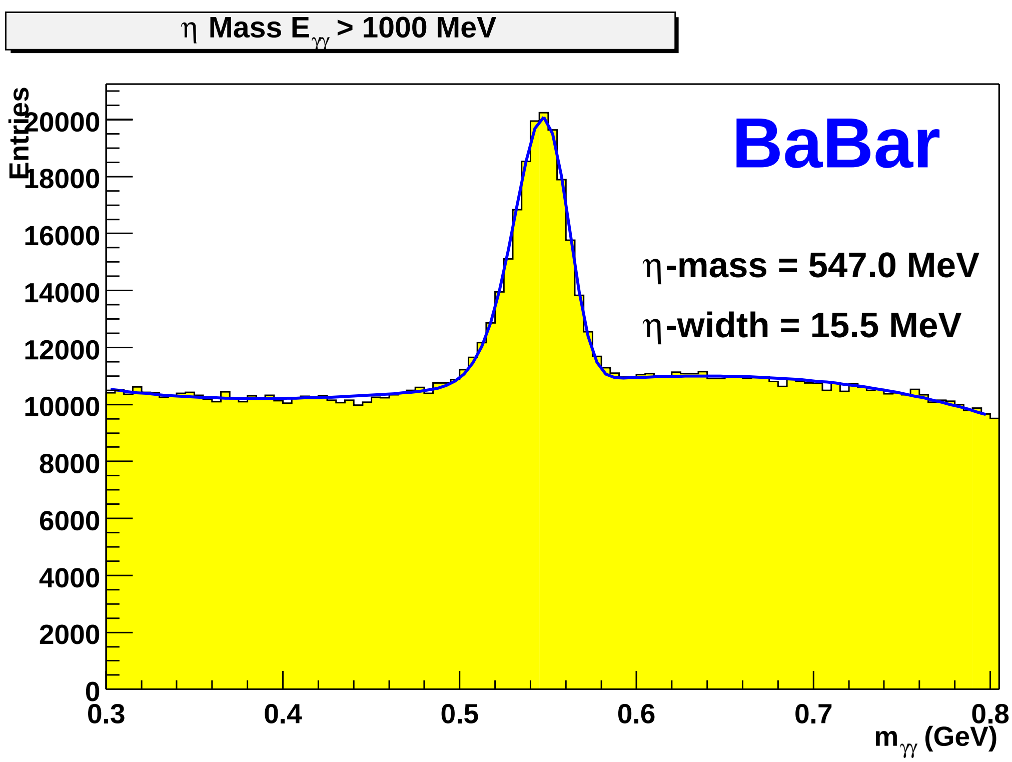
- Interpolate between bins with polynomials



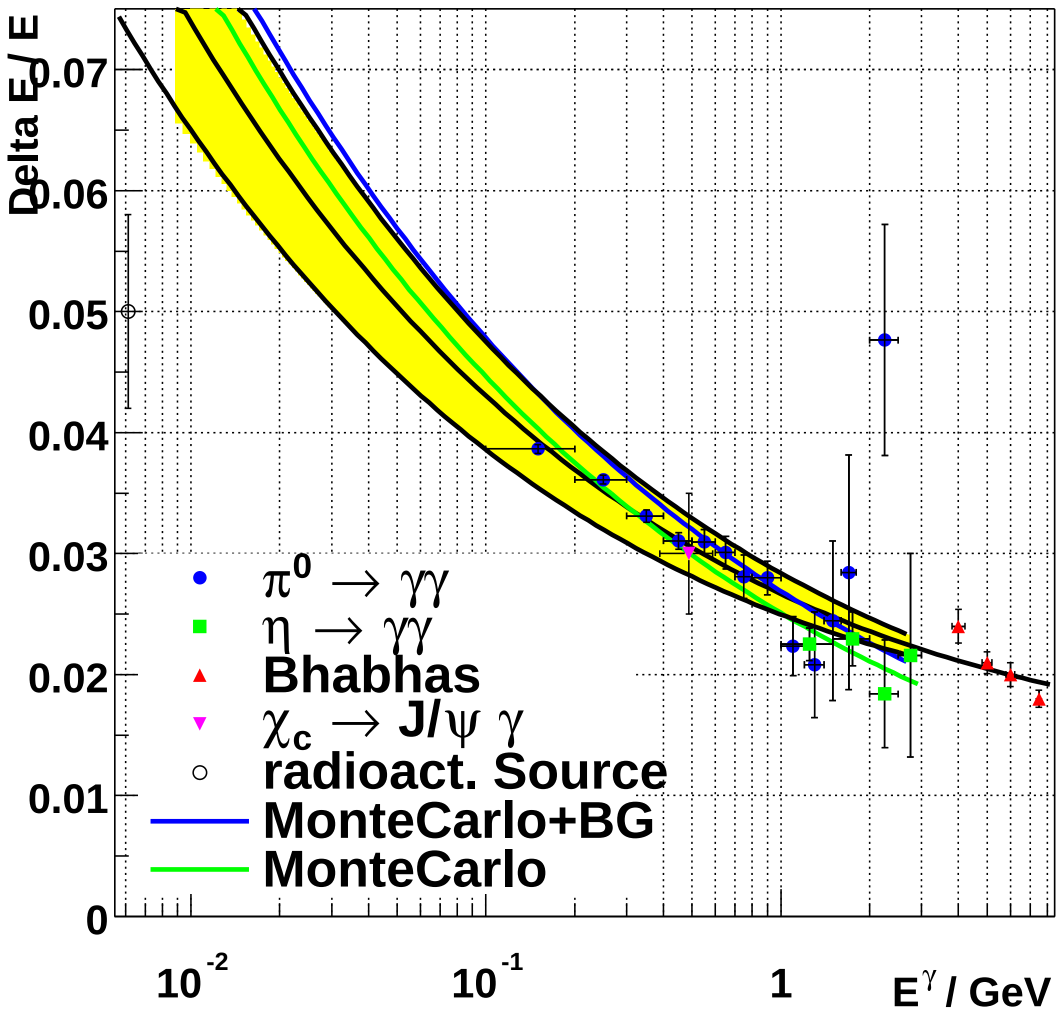
- Calibration function Monte Carlo (Run 1 cuts)
- Calibration function data Run 1
- Calibration function data Run 2
- Data points after correction Run 2

π^0 and η resolution





Energy resolution

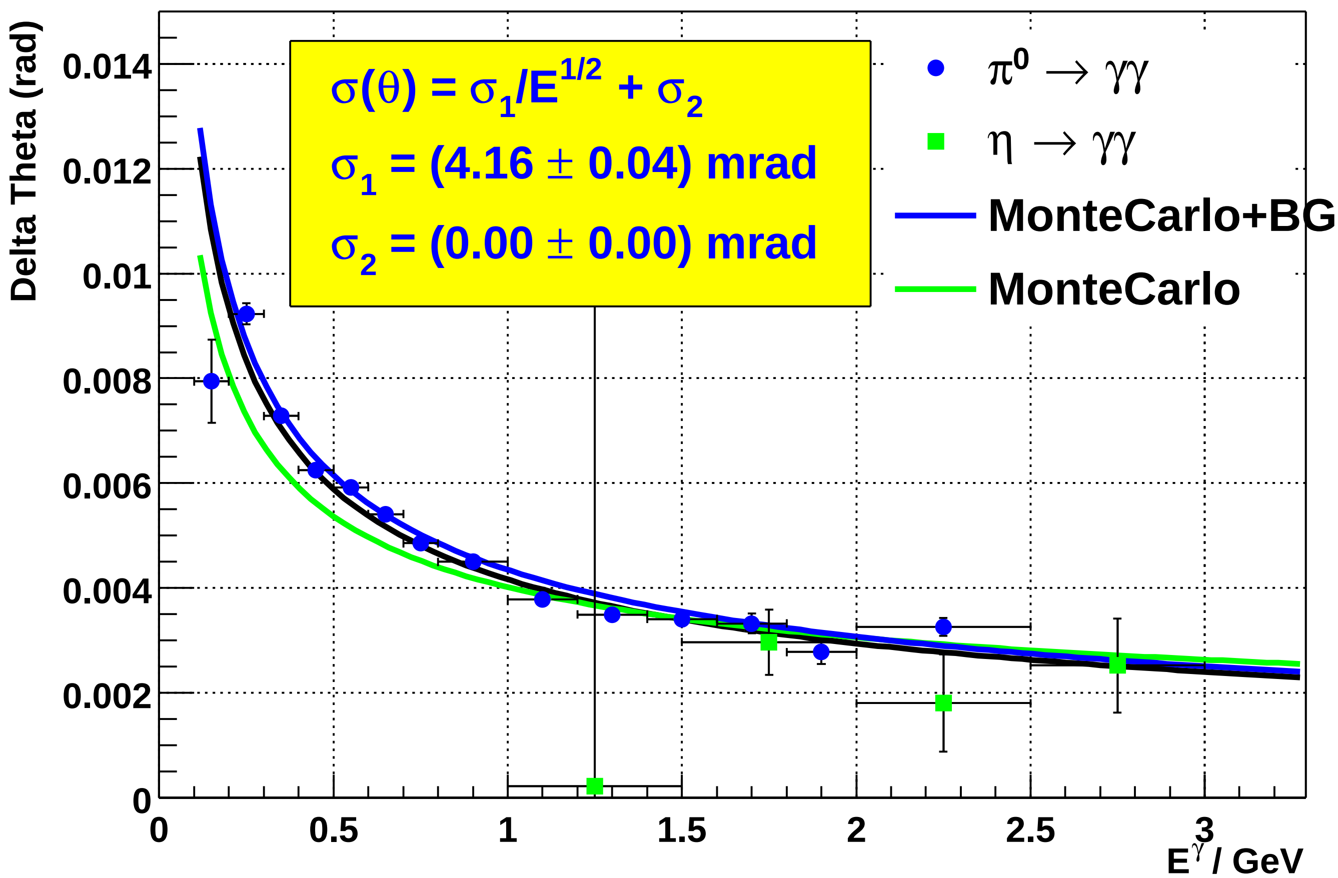


$$\frac{\sigma_E}{E} = \frac{\sigma_1}{\sqrt[4]{E}} \oplus \sigma_2$$

$$\sigma_1 = (2.30 \pm 0.03 \pm 0.3)\%$$

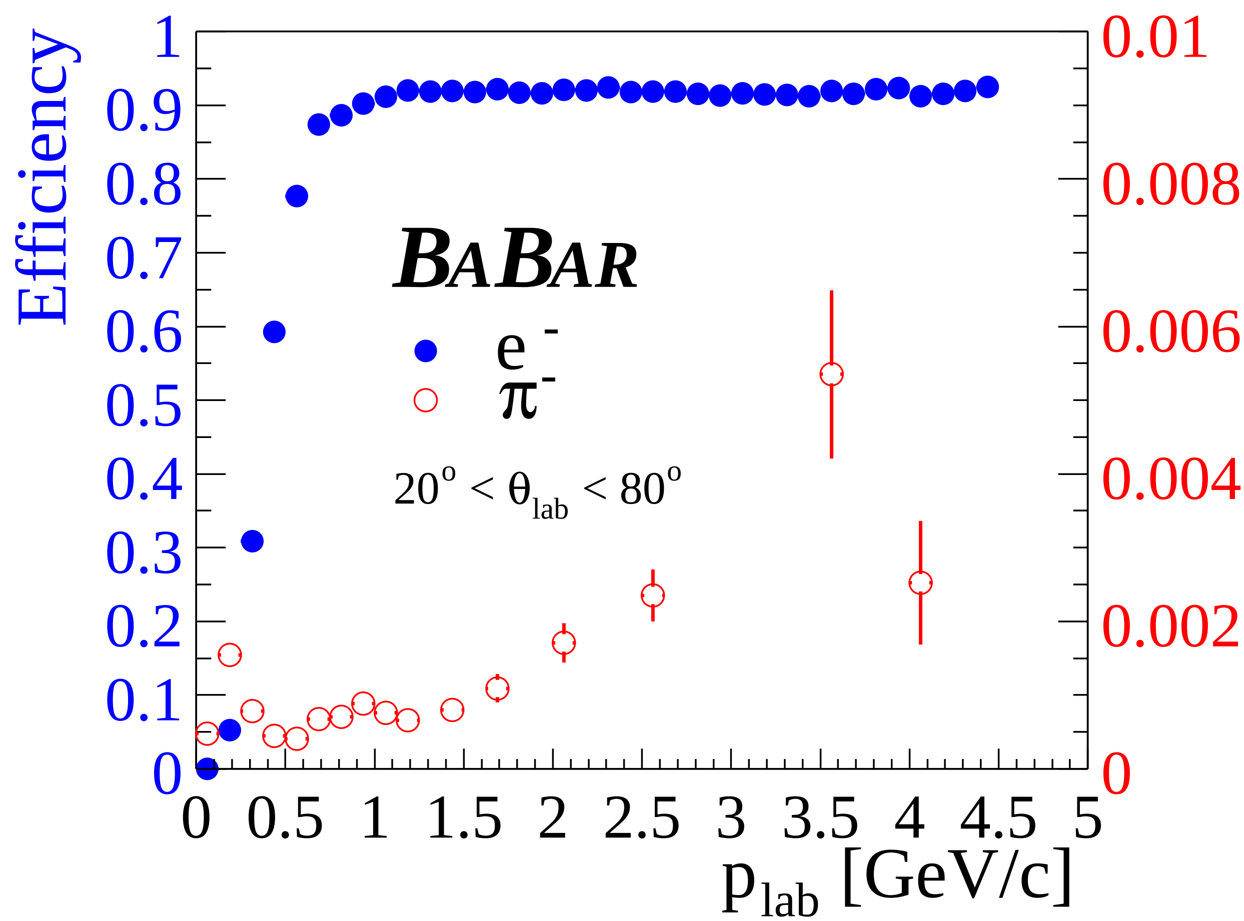
$$\sigma_2 = (1.35 \pm 0.08 \pm 0.2)\%$$

Angular resolution



Electron Identification

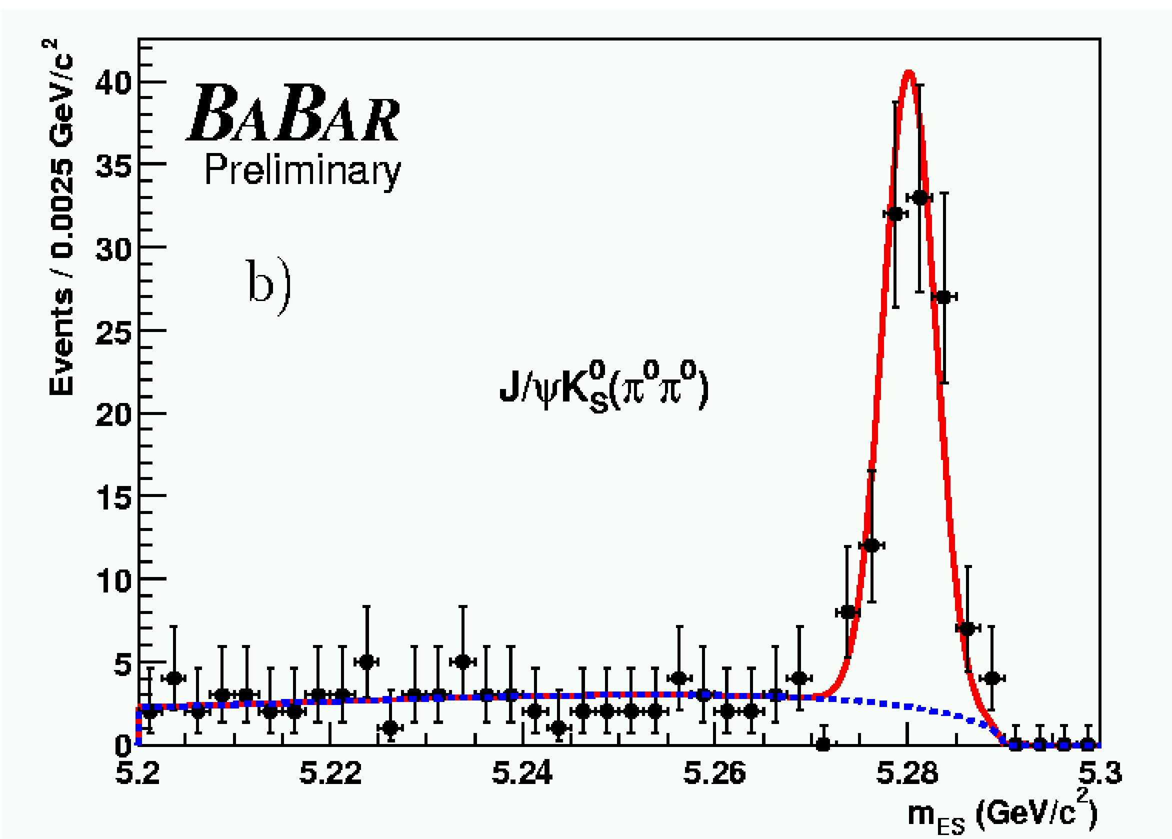
- The calorimeter is used for electron identification by cutting on
  - $E_{Calorimeter}/p_{Track}$
  - shower shape



- Electron efficiency
- π-mesons misidentified as electrons

Conclusion

- The Babar Electromagnetic Calorimeter has been working reliably for the past 2.5 years
- Performance is close to expectations
- Frequent calibration is necessary to compensate for changes in lightyield
- The calorimeter is a crucial component for doing physics with Babar



Signal for $B^0 \rightarrow J/\psi K_s$ with $K_s \rightarrow \pi^0\pi^0$