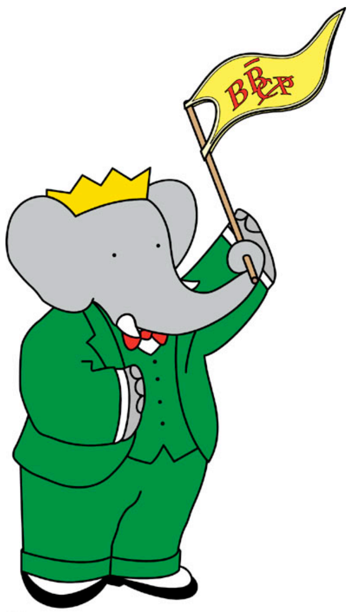
Performance and Operation of the CsI(Tl) Crystal Calorimeter of the BaBar Detector



Calor 08
30.May.2008
Pavia, Italy

Andy Ruland
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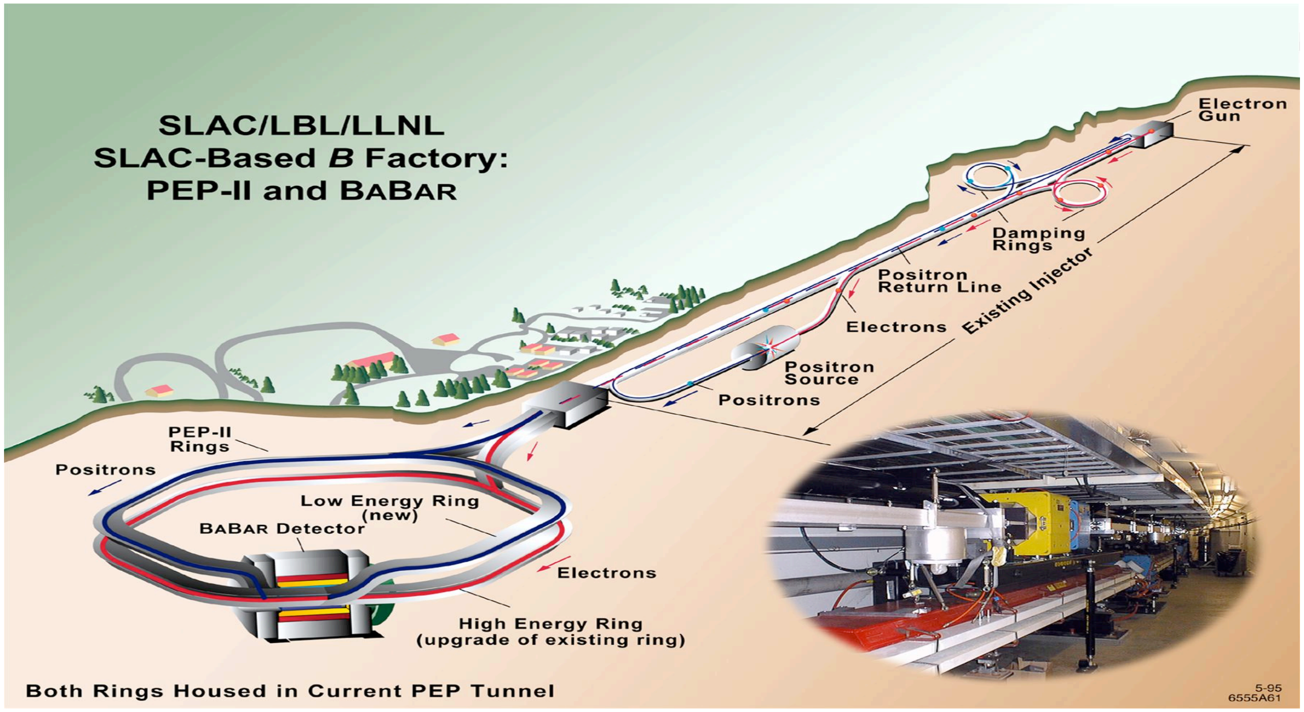
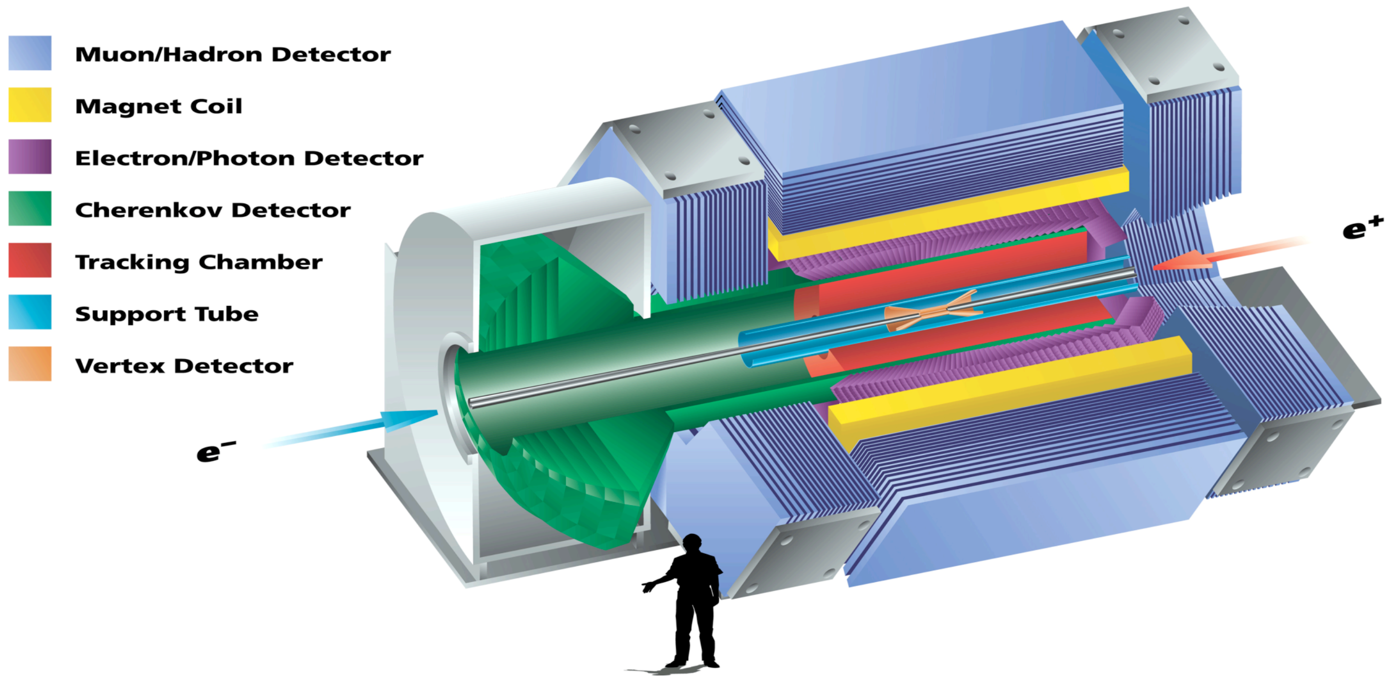
On behalf of the BaBar EMC group

The PEP–II *B*–Factory at SLAC



- Asymmetric e^+e^- collider
  - 9 GeV e^-, 3.1 GeV e^+ $\Rightarrow$ 10.58 GeV CM energy
  - $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$
  - Peak Luminosity: 12 x 10^{33} cm^{-2} s^{-1} (April 2008)
  - Data taking period ended in April 2008
  - Total Luminosity recorded: 531.4 fb^{-1}

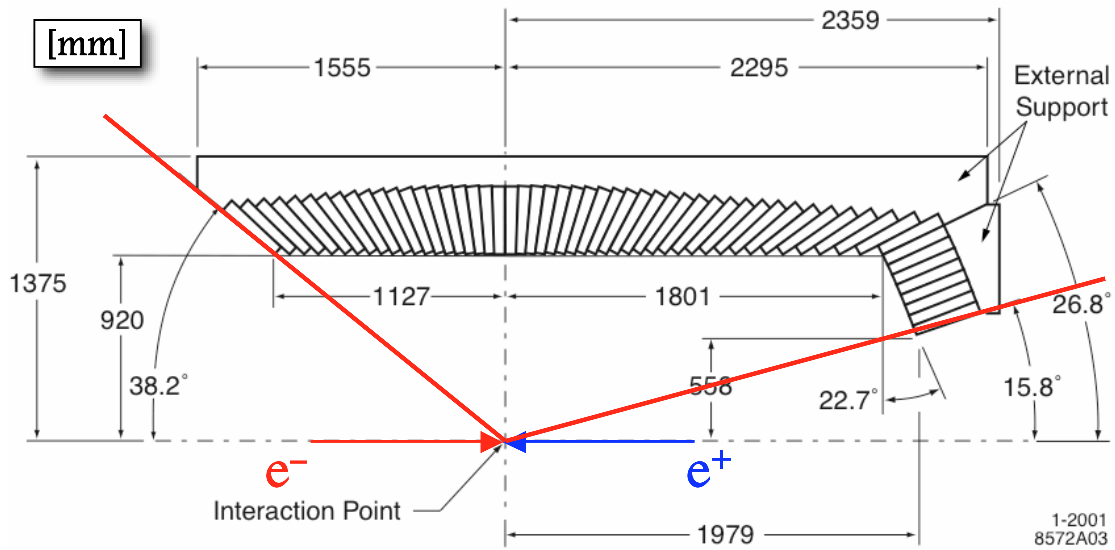
The BaBar Detector

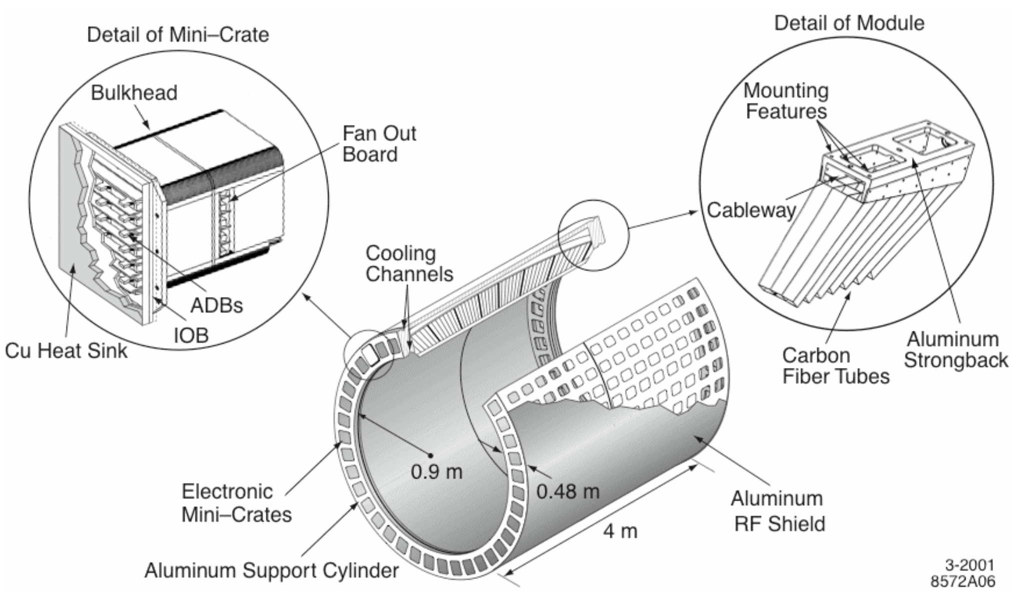


- BaBar physics program: mainly *B* physics, also τ and charm physics, and rare decay searches with high luminosity
- Calorimeter main goal is the reconstruction of:
  - Electrons
    - J/ψ meson reconstruction for $\sin(2\beta)$: $B^0 \rightarrow J/\psi\, K_s\ (J/\psi \rightarrow e^+e^-)$
    - For *B* flavor tagging
  - Photons from π^0/η and radiative decays

Calorimeter Design

- 6580 CsI(Tl) Crystals
- Barrel: 48 θ rings
  - 120 crystals/ring
- Endcap: 8 θ rings
  - 80/100/120 per ring
- 90% coverage in CM frame
- 14 mrad non–projectivity in θ
  - Fully covers Barrel/Endcap gap

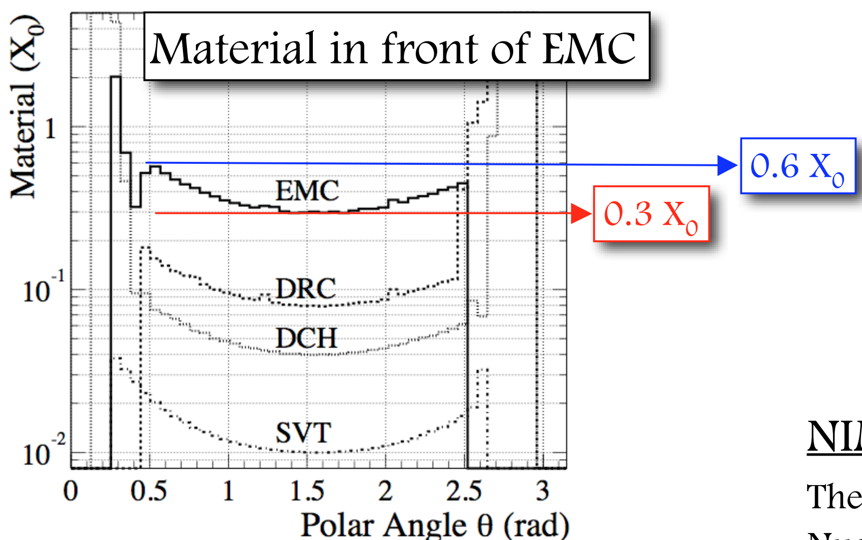


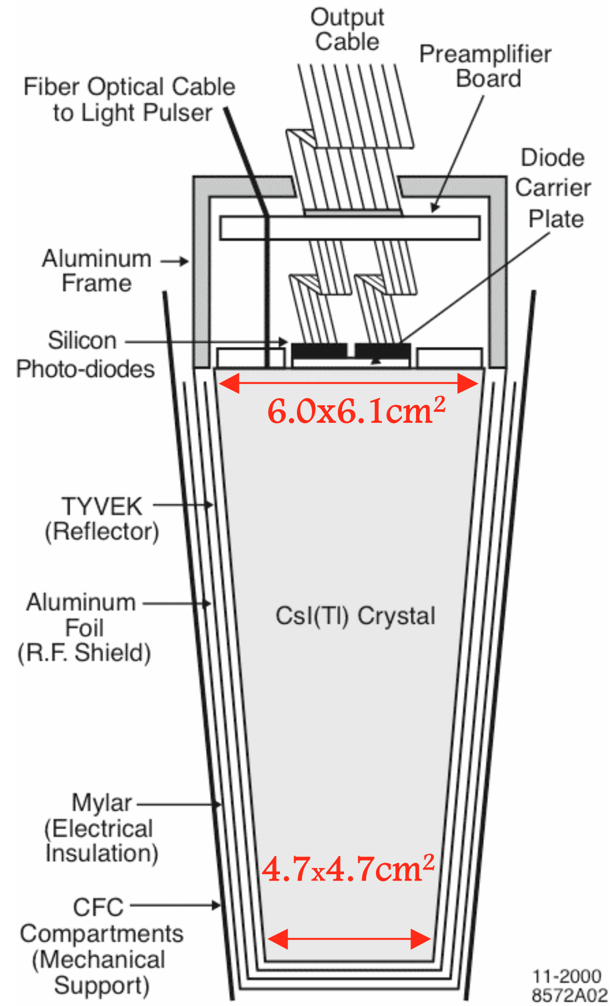


- Barrel:
  - 280 Carbon Fiber modules
    - 7 along θ / 40 along ϕ
    - 21 crystals / module
    - 7 crystals in θ / 3 crystals in ϕ
- Endcap:
  - 20 Carbon Fiber modules
    - 8 crystals in θ / 4,5,6 in ϕ
- 300 μm thick Carbon Fiber tube walls to hold crystals

CsI(Tl) Crystals

- 0.1% Thallium doping
- Trapezoidal shape
- Length:
  - 16.0 X_0 (bwd) and 17.5 X_0 (fwd)
- Tyvek wrapping for reflection (2x 165µm)
- Al foil and Mylar wrapping for electrical isolation
- 2 PIN Si photodiodes (2x1 cm^2)
  - Epoxied to 2x2 cm^2 polystyrene plate at crystal rear
- 2 preamps in readout box above crystal



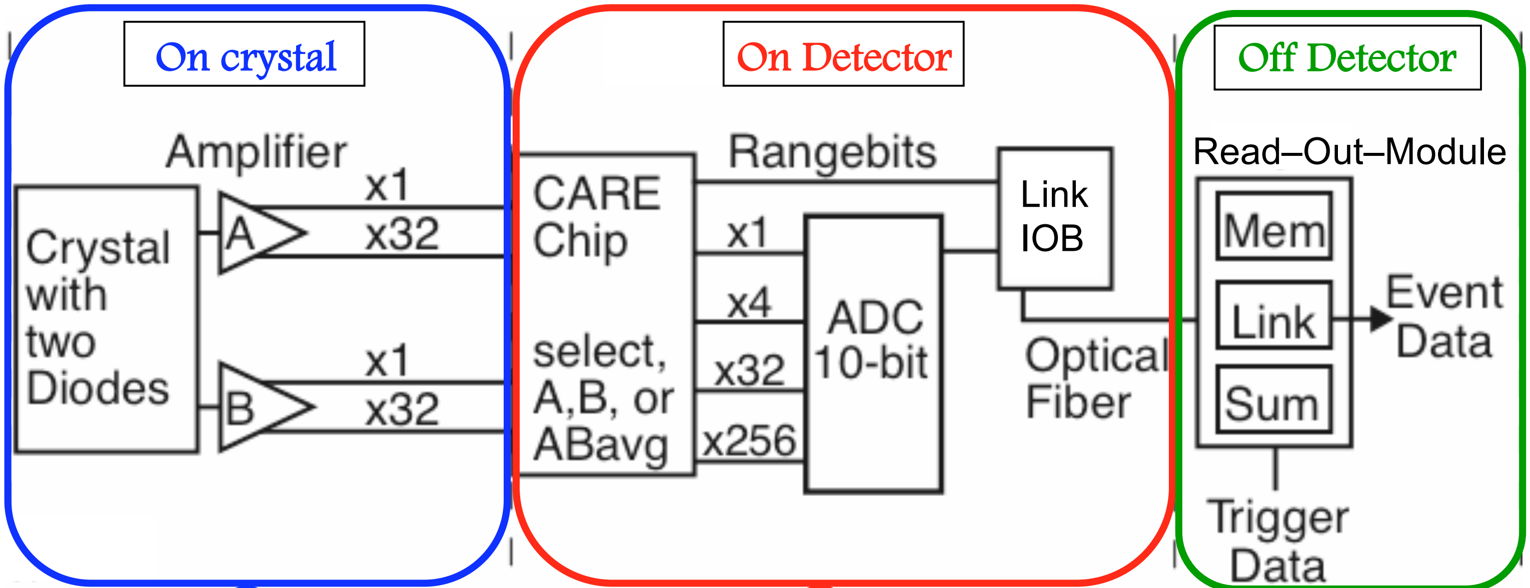


<u>NIM article</u>

The *BABAR* Detector, B. Aubert *et al.*,
Nucl. Instrum. Methods Phys. Res., Sect. A **479**, 1(2002)

Readout Electronics

Data Readout Chain



- 2 fold redundancy
- x1, x32 amplification
- 13 bit dynamic range

- x4, x256 amplification
- Choose best range diode
- 10 bit ADC, 2 bit range
- Data sent via optical fiber

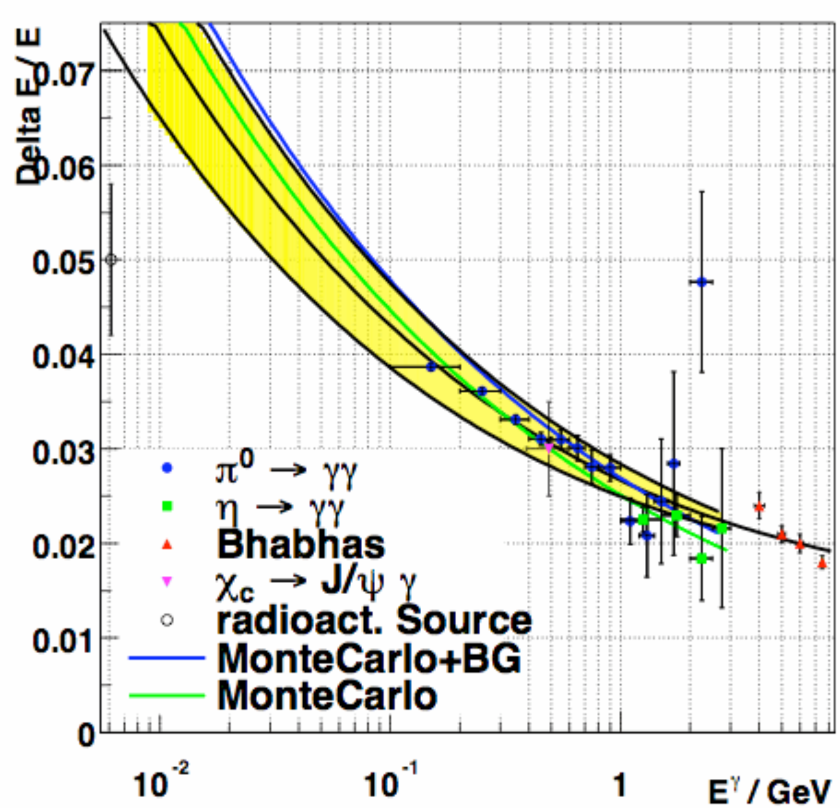
- Untriggered Readout
- FEX and Filtering
- Correct for pedestal gain
- Convert to full E range
- Copy to trigger
- If accepted, read E and t

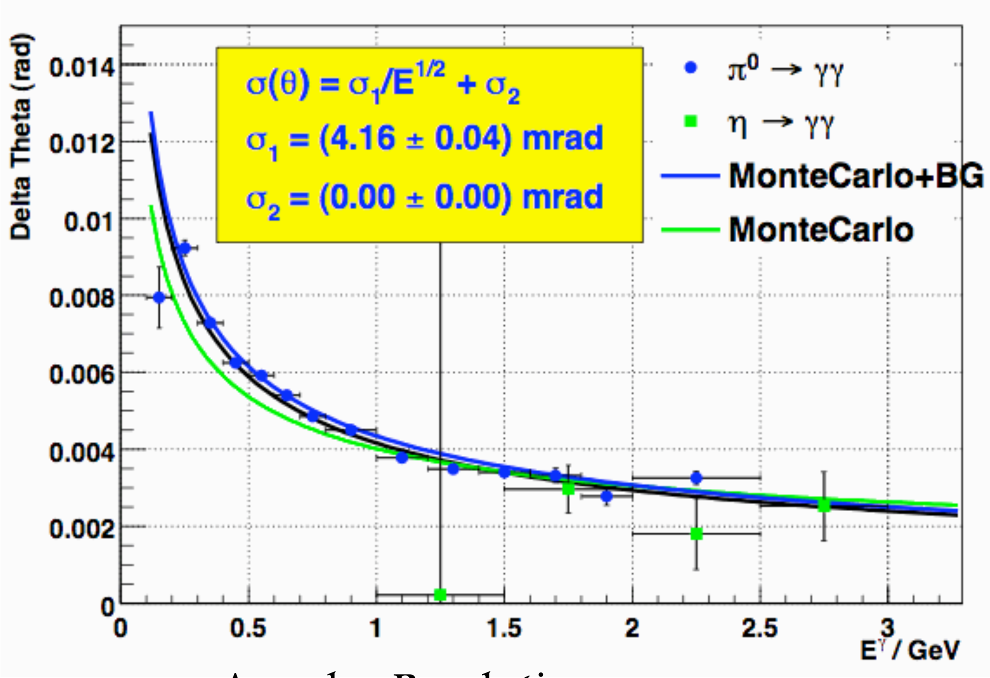
Calorimeter Performance

- Energy Resolution:

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

- $\sigma_1 = (2.30 \pm 0.03 \pm 0.3)\%$
- $\sigma_2 = (1.35 \pm 0.08 \pm 0.2)\%$



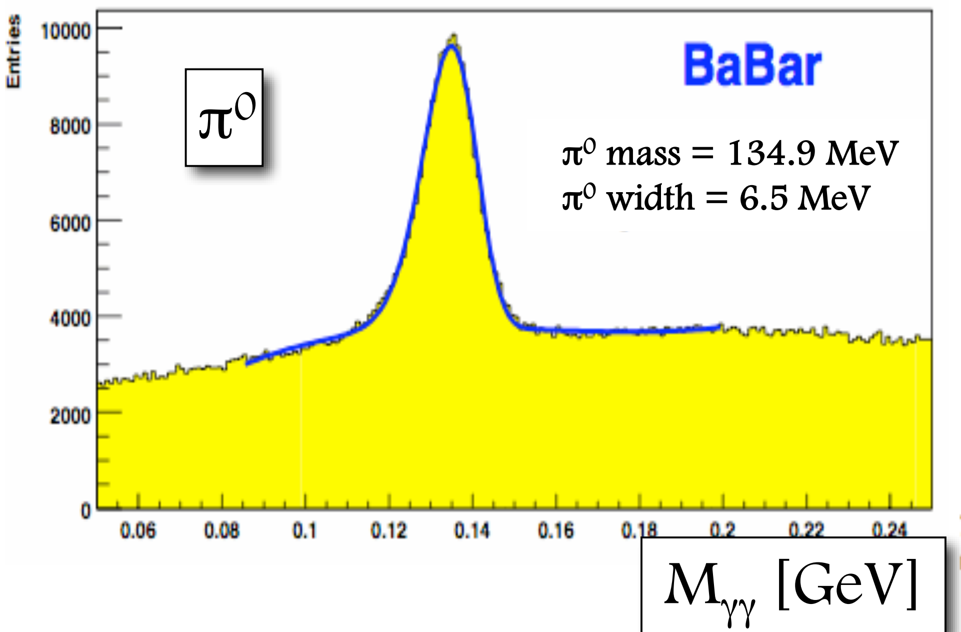


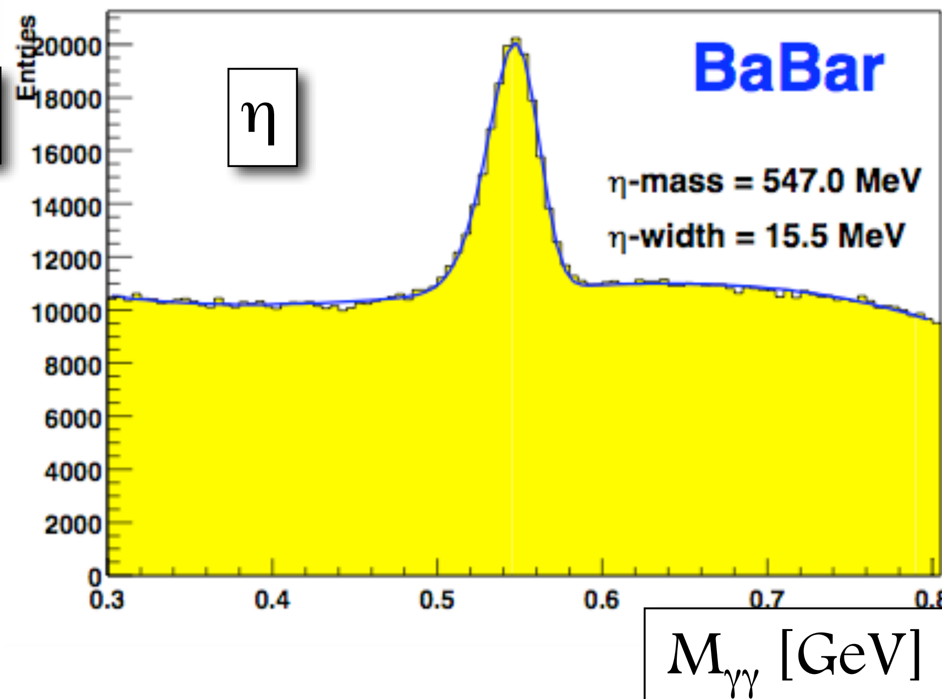
- Angular Resolution:

$$\sigma(\theta) = \frac{\sigma_1}{\sqrt{E}} \oplus \sigma_2$$

- $\sigma_1 = (4.16 \pm 0.04\ )\mathrm{mrad}$

π^0 and η Response



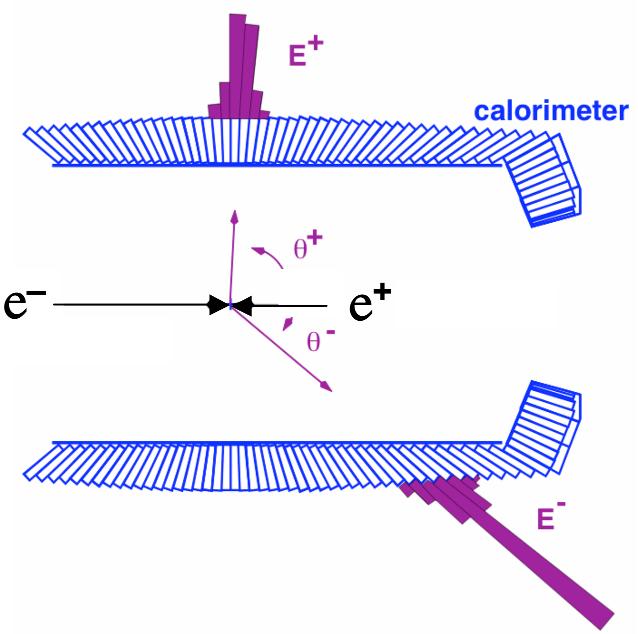


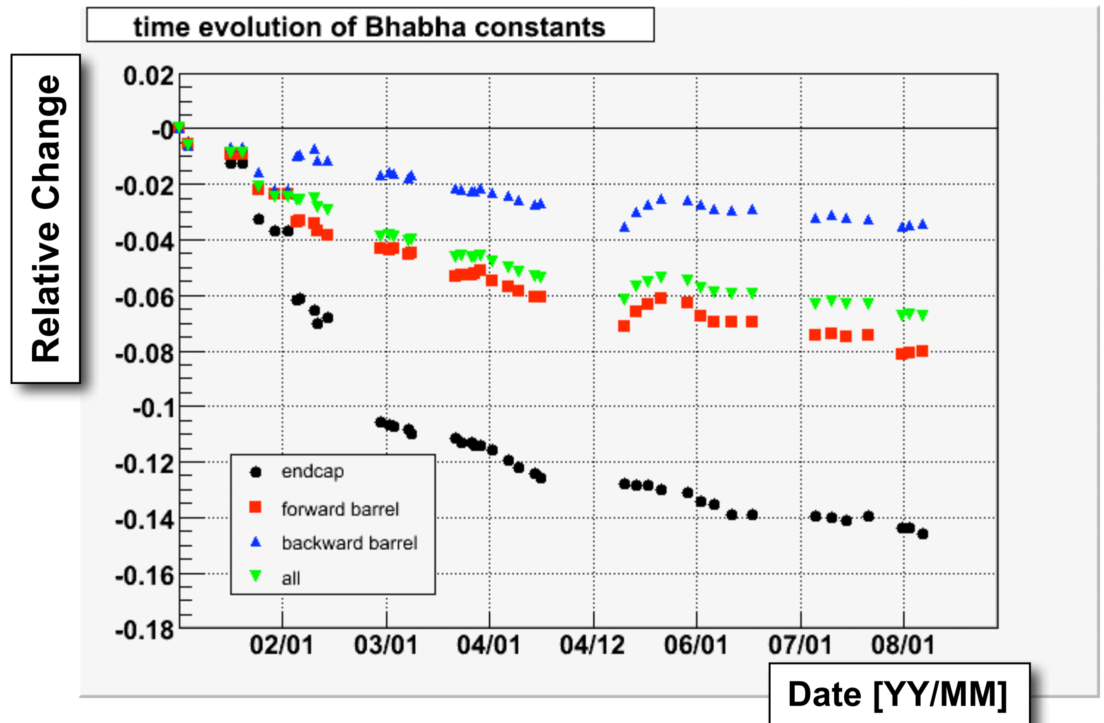
- 2 photon invariant mass plots for hadronic events
  - $E\,\gamma > 30$ MeV
  - $E\,\pi^0 > 300$ MeV

Calibrations

- <u>Electronics Calibrations</u>
  - Linearize response of on–detector electronics by charge injection to preamp inputs
    - Determines pedestals and overall gain
    - Corrects for cross talk between crystals
  - Performed during beam down times and after hardware replacement:
    - ~2/month and requires ~1hr. with no beam.
- <u>Single crystal calibrations</u>
  - Light yields and crystal uniformities change through radiation damage
  - Radioactive Source $\Rightarrow$ Low energy crystal response
  - Bhabha $\Rightarrow$ High energy crystal response
  - Lightpulser checks readout path
- <u>Cluster energy calibrations</u>
  - Relate $E_{cluster}$ to energy of incident $e^{\pm}/\gamma$
  - Deposited E depends on leakage that is a function of (θ,ϕ) and the detector material
  - $\pi^0 \rightarrow \gamma\gamma \Rightarrow 70$ MeV $< E_\gamma <$ 2 GeV
  - $e^+e^- \rightarrow \mu^+ \mu^- \gamma \Rightarrow 400$ MeV $< E_\gamma <$ 6 GeV
  - See Jörg Marks' talk for details on the cluster calibrations

Bhabha Calibration





- Used for single crystal calibration at high energies: 3–9 GeV (~ monthly)
  - Deposited cluster energy is constrained to equal prediction of GEANT based MC
- Solve linear equations so that c_i minimizes:

$$\chi^2 = \Sigma_k \frac{(\Sigma_i (c_i E_i^k) - E_{dep}^k)^2}{(\sigma^k)^2}$$

i – crystal index, k – cluster index

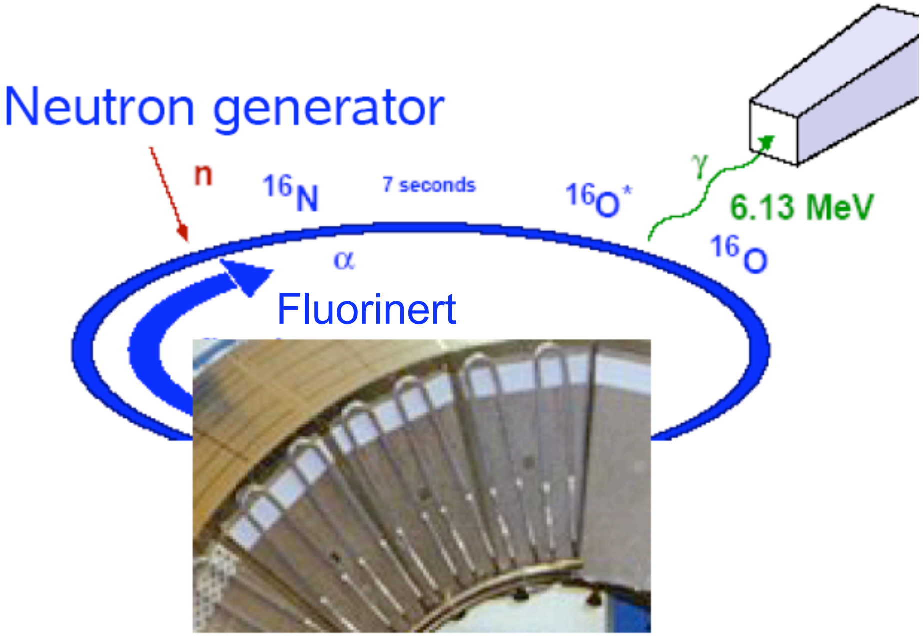
c_i – calibration constant

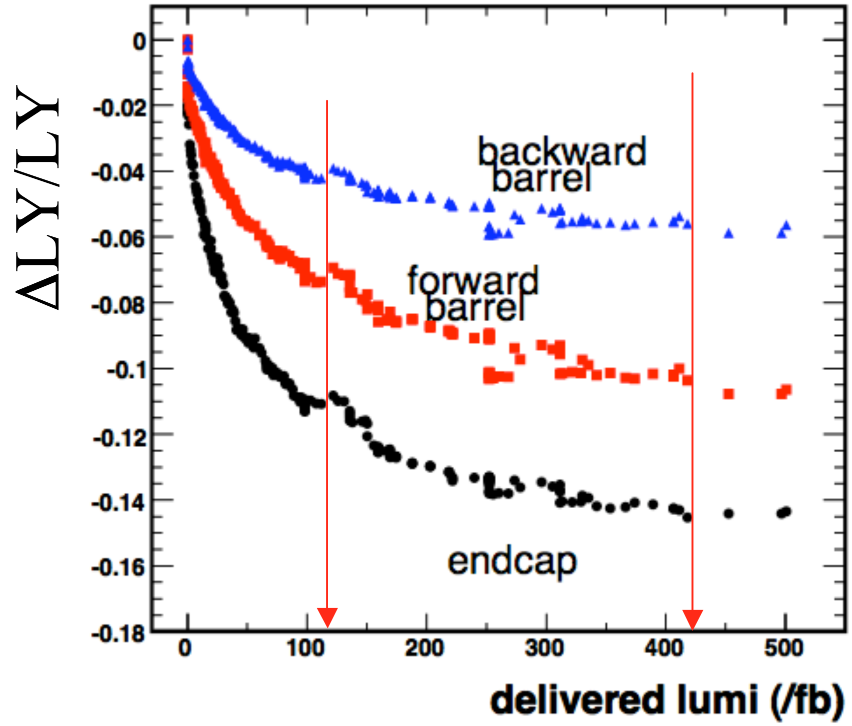
E_i^k – raw energy in crystal i

E_{dep}^k – deposited cluster energy from MC

σ^k – error

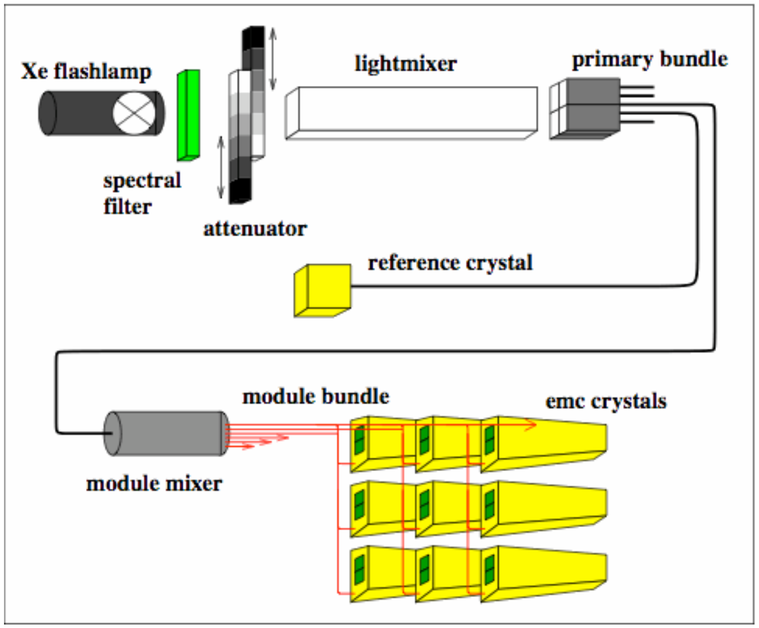
Radioactive Source Calibration

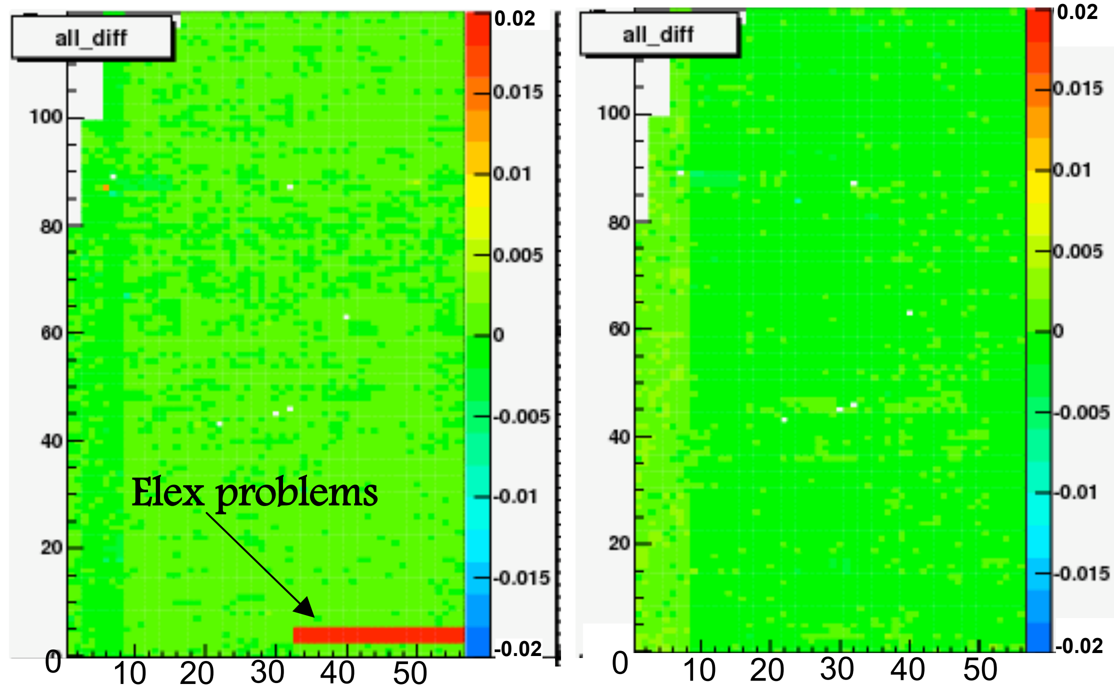




- Radioactive source used to set the low energy response for each crystal
  - n irradiated Fluorinert circulates through piping at front face of crystals
  - 6.13 MeV photon from $^{19}F + n \rightarrow {}^{16}N + \alpha$, $^{16}N \rightarrow \beta + {}^{16}O^* \rightarrow {}^{16}O + \gamma$
  - ^{16}N: $\tau_{1/2} \sim 7s$
- 15–30 minute runs taken every 4±1 weeks with no beam in machine
- Resolution of constants: 0.33 %
- 2 failed generators over 10 year data taking period 2003, 2007 (red arrows)

Lightpulser Monitoring

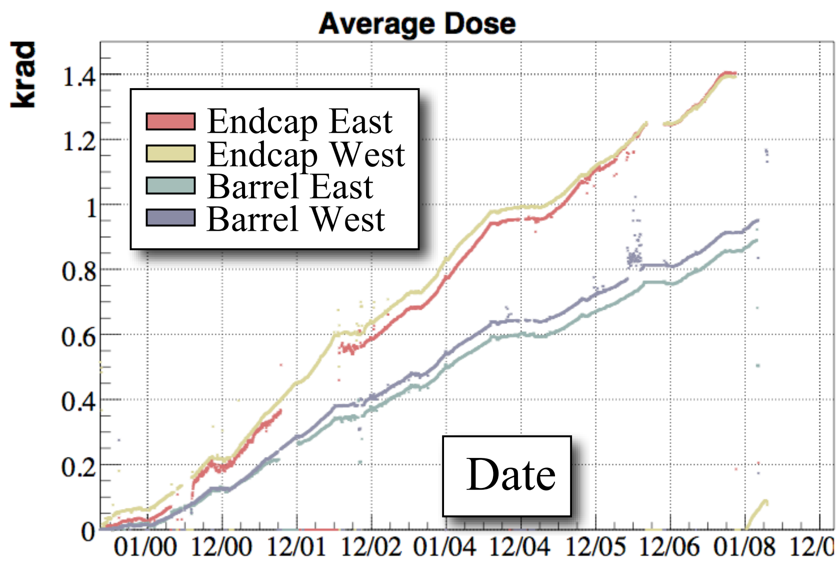


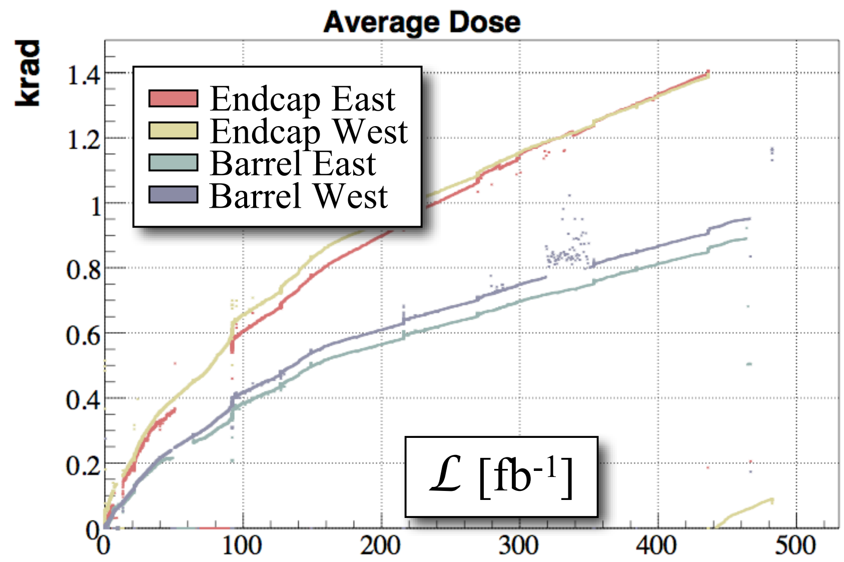


Run–to–Run xtal mean differences

- Daily lightpulser calibrations cover complete readout path from diodes to DAQ system
  - Time required for calibration: ~few minutes
- Xe lamp spectrum matched to emission freq. of CsI(Tl) scintillation
  - Allows monitoring of relative change in crystal response between calibrations
  - Also for diagnostics on electronics read out

Radiation Monitoring

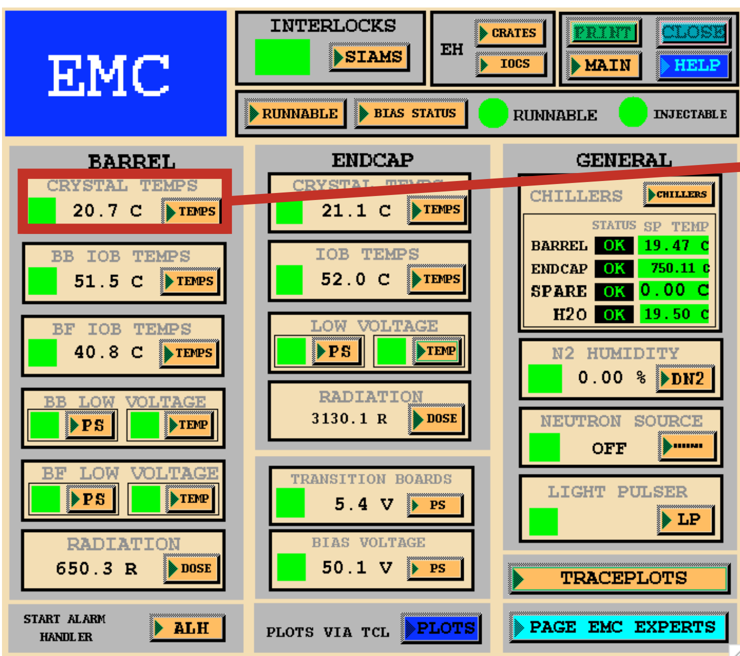




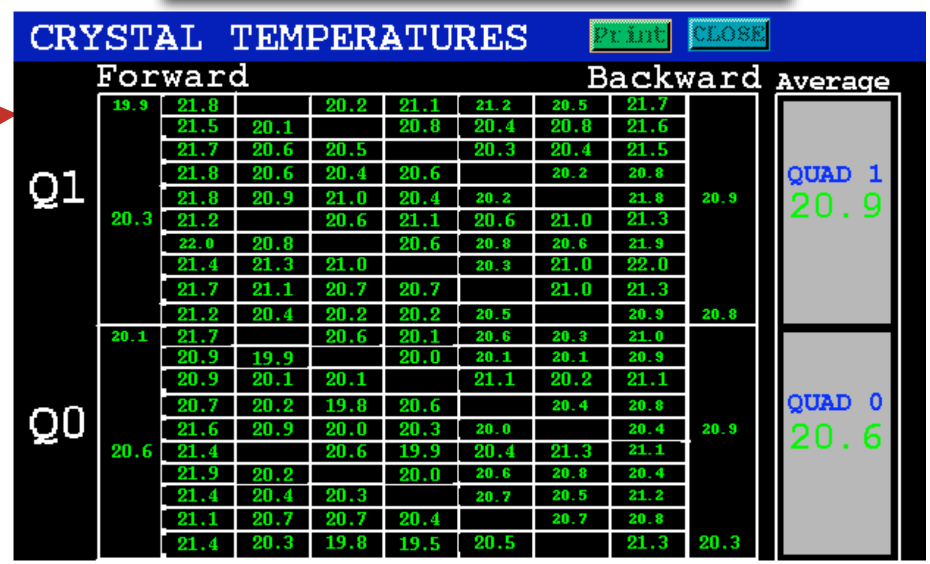
- Radiation induced optical losses produce non uniform change in light yield along crystal length which degrade energy resolution.
- 116 p–channel MOSFET transistors arranged at the front face of crystals
  - Barrel: 56 / Endcap: 60 RadFETs
- Map integrated dose absorbed by different regions of calorimeter.
  - Scattered beam particles interactions with residual gas in vacuum chamber
    - E ~few MeV
  - Radiative Bhabhas

Hardware Monitoring

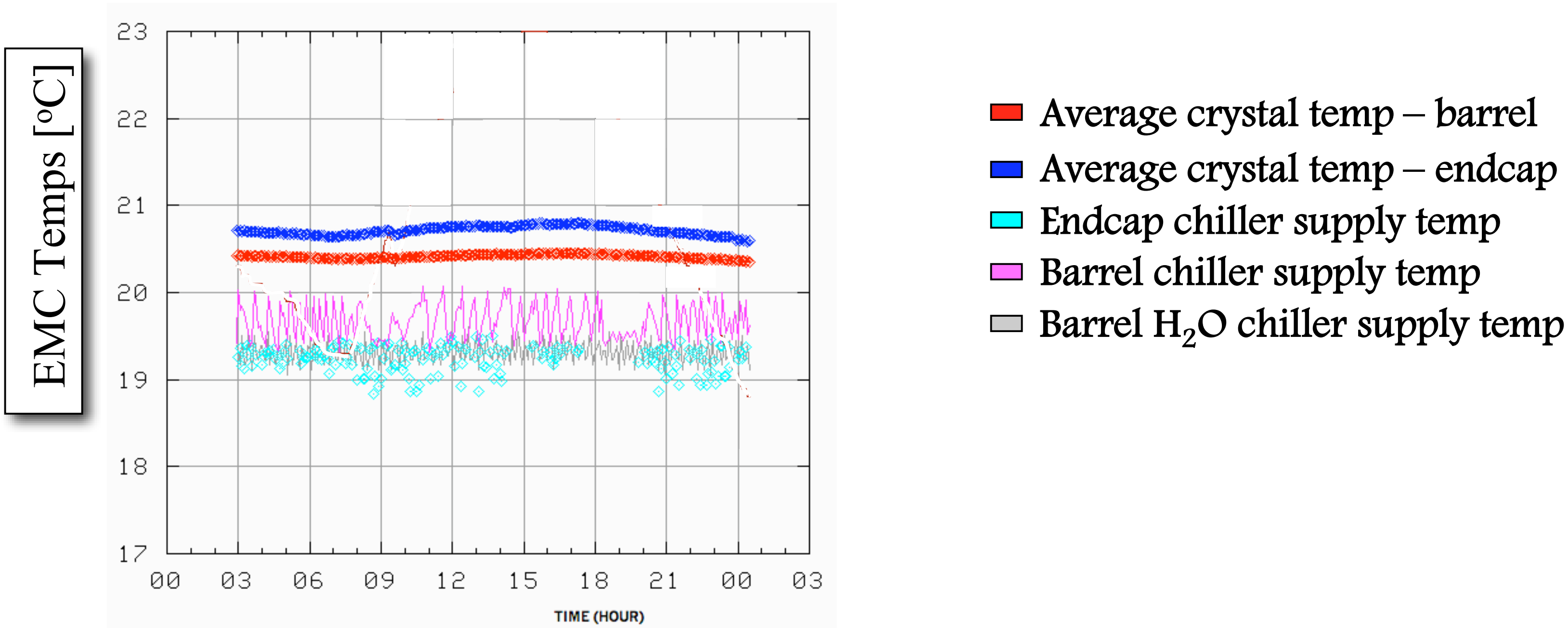
- Hardware status is monitored in real time using EPICS
- Monitoring takes place for 100's of parameters
  - Temperature of electronics and crystals
  - I/V of electronics power supplies
  - Temperature and flow rates of chillers
- Readings archived in database
- All alarms are immediately passed to shifters and EMC on–call manager
  - Depending on severity, problems can be remedied within minutes



Barrel Crystal Temperatures

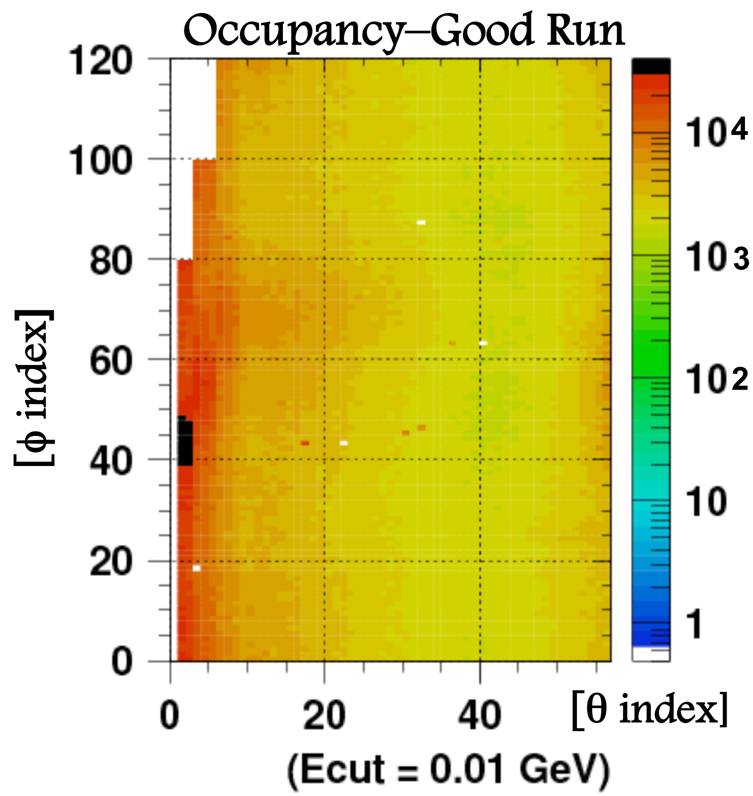


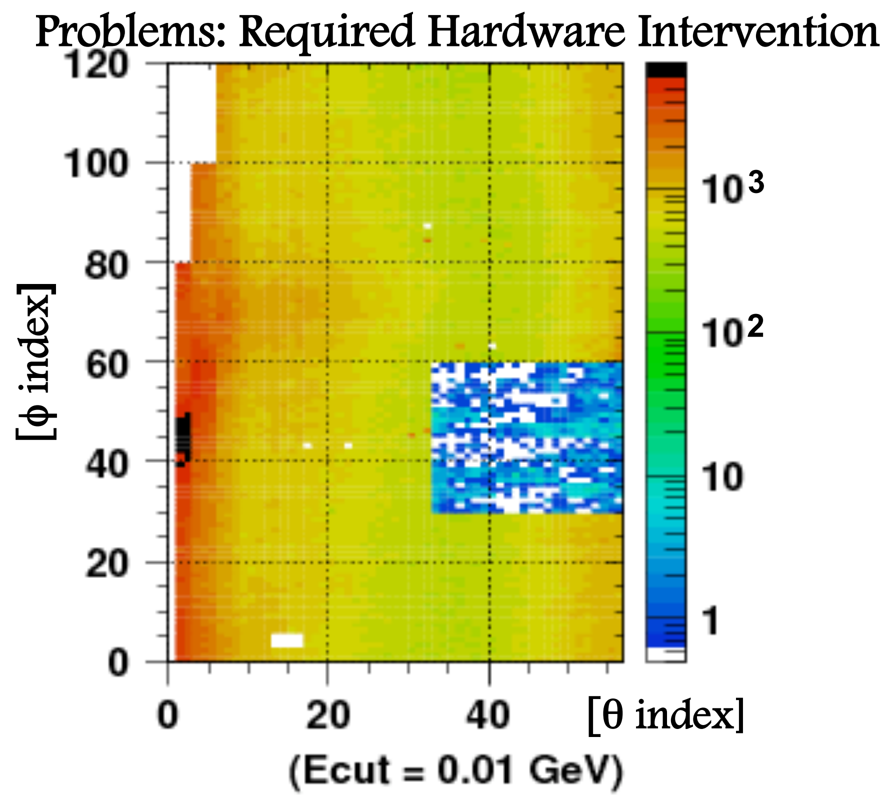
Environmental Monitoring



- Temperature regulation for integrity of crystal ↔ diode glue joints and LY of crystals. (~20±1° C)
- Electronics and Crystal Cooling maintained by 2 sets of chillers
  - 3 independent Fluorinert chillers: 1 barrel, 1 endcap, and 1 spare that can be switched on to either barrel/endcap circuit or both
  - Deionized Water chiller for barrel on–detector electronics
  - Backup chiller system (BCS) can replace both water and Flourinert chillers in emergencies

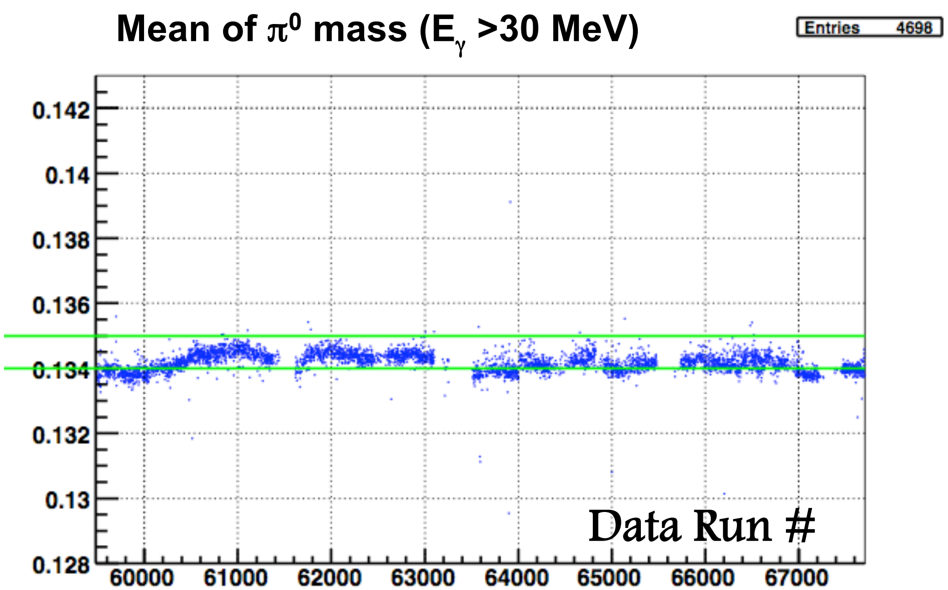
Data Monitoring–1

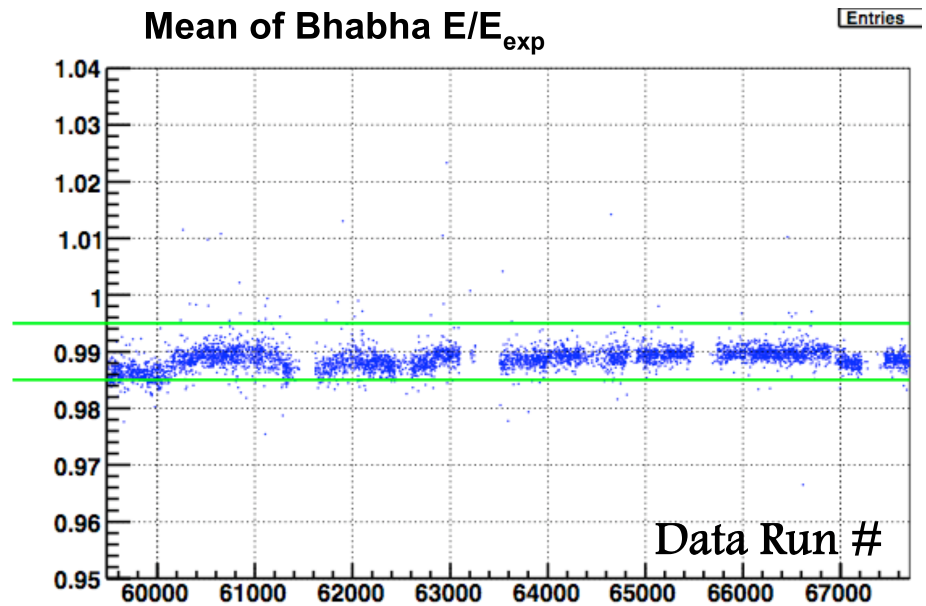




- Live Data Monitoring
  - During data taking checks made ~15 min.
  - Checks are made on occupancies, energy–time structure, energy/multiplicity profiles between live data and reference plots.
  - Automated comparisons made between previous runs
  - 3 permanently dead crystals and typically 0–24 temporarily dead channels

Data Monitoring–2





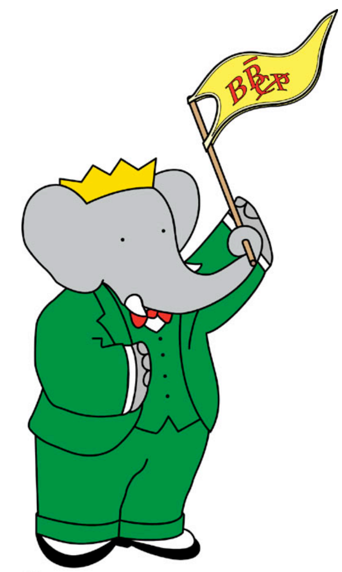
- Event reconstruction monitoring
  - Done offline and run by run
    - Typical runs 45–55 minutes in length (Each blue dot represents a single run)
    - Above data from Nov 2005 through Aug. 2006
  - E/p of Bhabha's, π^0 mass and width, occupancy multiplicities
  - Daily checks

Operational Activities

- For the last several years the EMC has been in a stable operation and maintenance mode
  - Result of first years hard work and automation of monitoring
- Typical maintenance activities:
  - On detector electronics (access required for repair)
  - ADB board (12 crystals) or IOB board (72 crystals) replacement
    - Typically 1–2 boards replaced per access, with more problems after down times
    - Requires Detector access (~4+ hrs) so planned with PEP down time.
    - Can mask channels out of data taking if no access can be made (~5 min)
    - Several water leaks from cooling lines which caused electronics damage
  - Off detector electronics (no access required)
    - Power supplies occasionally trip, cause data taking to stop
    - Power cycling, reseating, swapping with spares are normal (few minutes)
  - Other Hardware
    - Chiller maintenance (~weekly)
- 1 major intervention
  - BaBar installed upgrade to muon system in Fall 2006 which required uncabling and removal of most of the front end calorimeter electronics for a period of 3 months.
    - 280 electronics boards remove/changed and all cabling rerouted
    - Not a single channel lost.

Summary

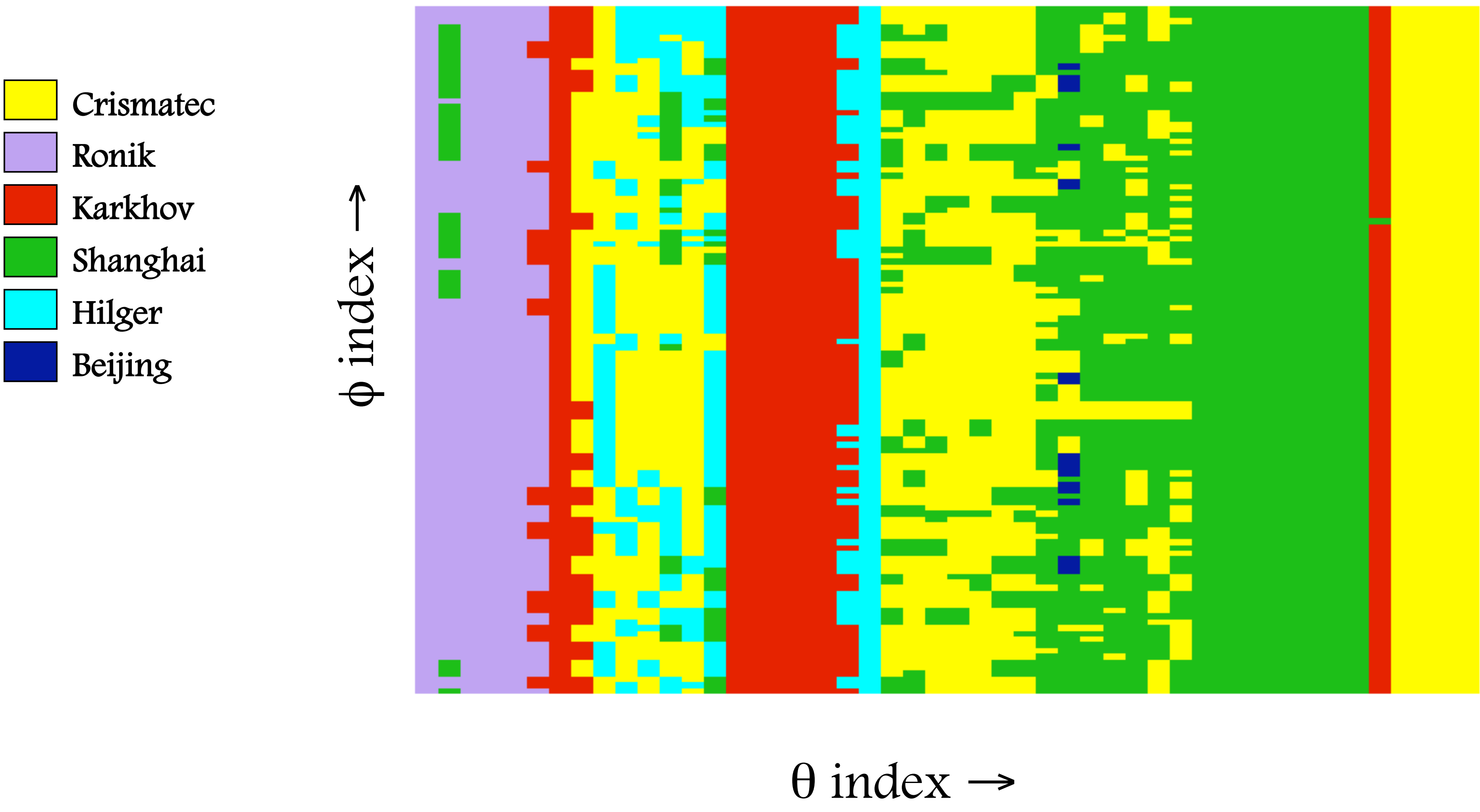
- 10 years of operation completed in April 2008
- High efficiency and excellent data quality for the past several years.
- Problems encountered in last years were mostly repair and maintenance
- High luminosity achieved by PEP–II did not adversely affect EMC performance
- For the future:
  - SuperB factory has planned for reuse of barrel crystals and support structure for their electromagnetic calorimeter.



Backup Slides

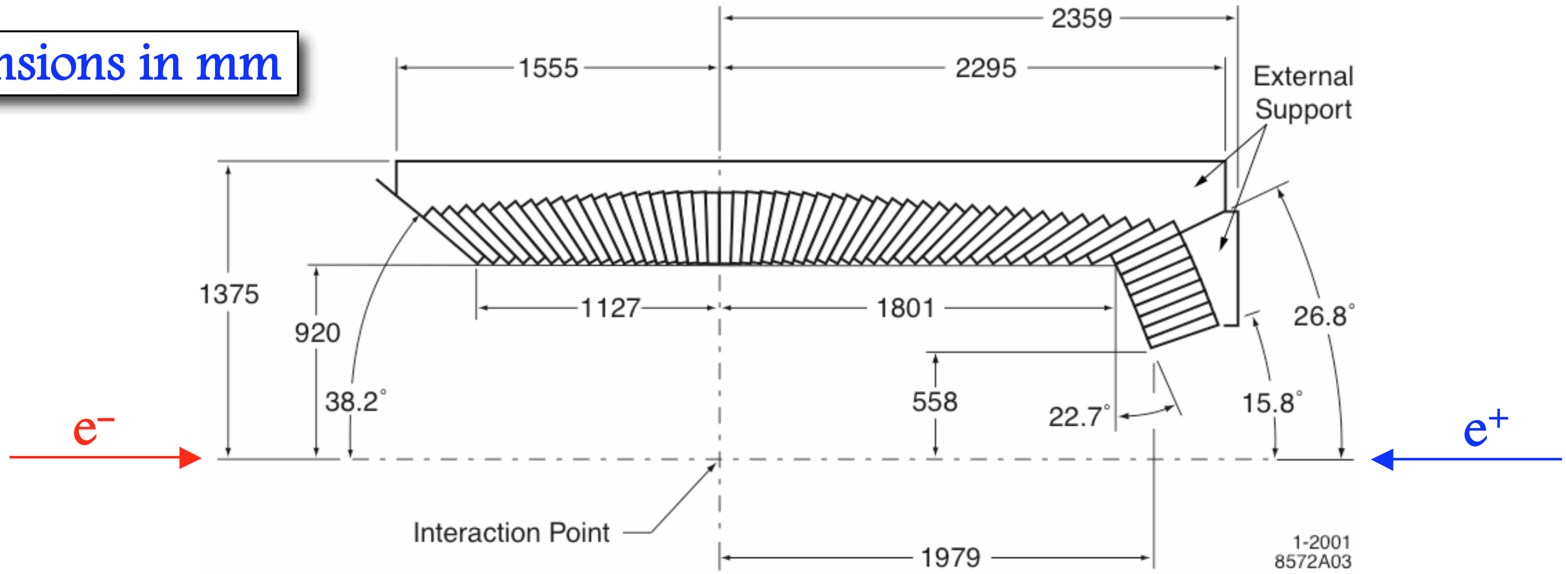
Calorimeter Crystals

- Distribution of crystals by vendor inside the barrel



Calorimeter Design

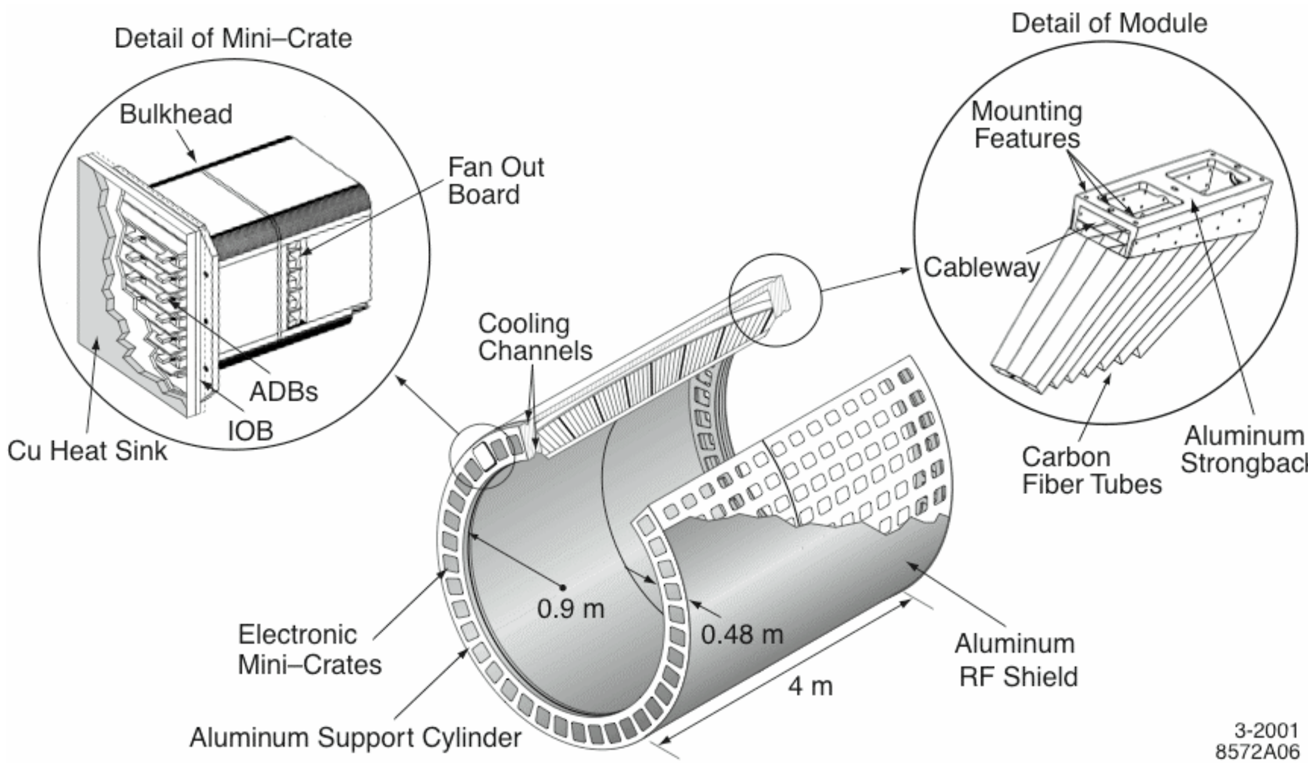
dimensions in mm



- 6580 CsI(Tl) crystals – 0.1% Thallium doping
- Barrel: 48 rings along θ and 120 crystals/ring
- Endcap: 8 rings along θ with 80/100/120 crystals/ring
- Angular coverage
  - Polar angle: $-0.785 < \cos(\theta) < 0.962$
  - Azimuthal: 360°

  } 90% coverage in CM frame
- Crystals are non–projective in θ by 15mrad to minimize unmeasured energy loss due to inactive material between crystals.
  - Barrel↔Endcap gap fully covered by non–projectivity

Calorimeter Support Structure



- Barrel:
  - 280 carbon fiber modules → 7 along θ ; 40 along ϕ
  - Per module: 7 crystals in θ, 3 crystals along ϕ
- Endcap:
  - 20 carbon fiber modules → 8 crystals along θ ; 4/5/6 along ϕ

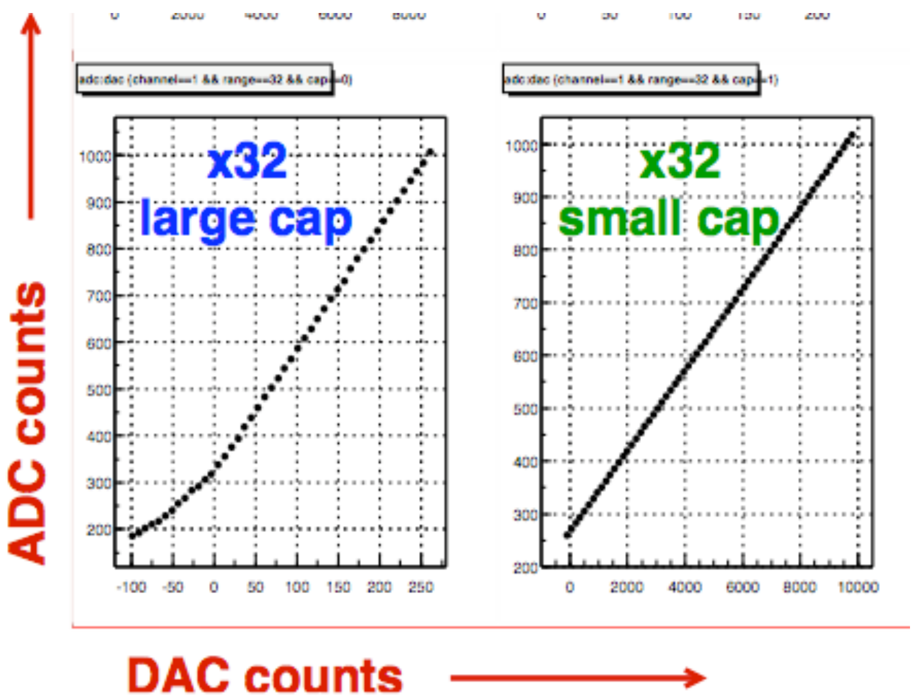
CsI(Tl) Crystal Properties

CsI(Tl) Properties	
Radiation Length	1.85 cm
Molière Radius	3.8 cm
Density	4.53 g/cm^3
Light Yield	50,000 γ/MeV
Ligh Yield Temp. Coeff.	0.28%/°C
Peak Emission (λ_{max})	565 nm
Refractive Index (λ_{max})	1.80
Signal Decay Time	680 ns (64%)
	3.34 μs (36%)

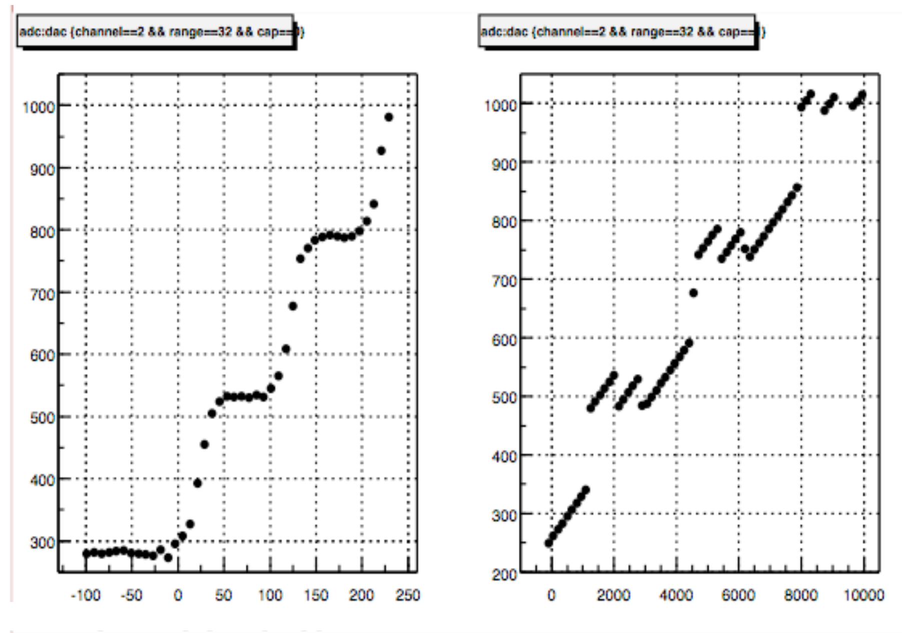
Electronics Calibration

- Calibrate gains by injecting known charge into preamps
- Different capacitors used to cover entire ranges (x1/4/32/256)
- Fit all 4 ranges simultaneously

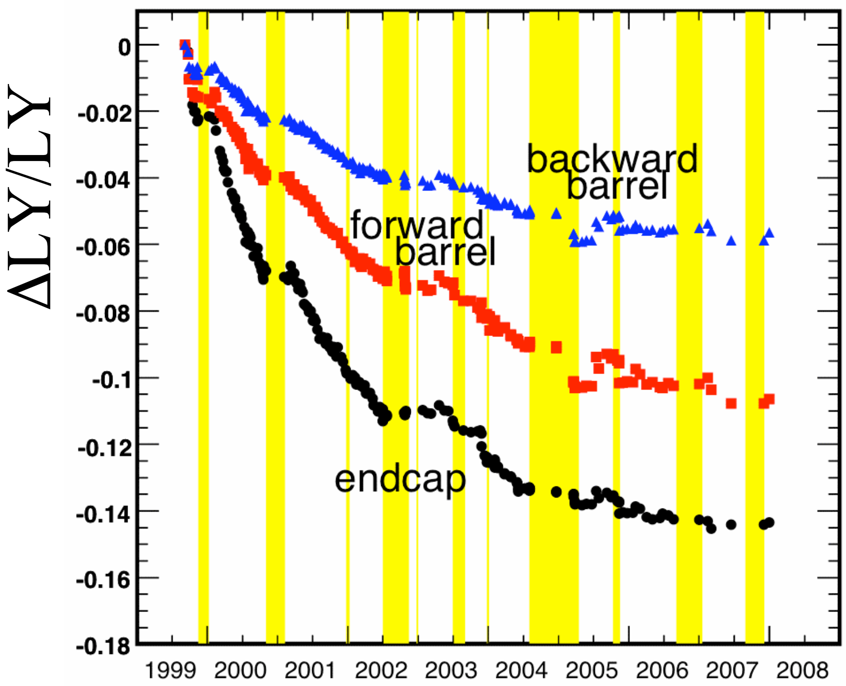
Good Channel



Problem Channel



Radioactive Source Calibration



[Year]

- Left Plot:
  - Relative lightyield change over lifetime of BaBar.
  - Yellow bands represent periods of no collisions