The BABAR Electromagnetic Calorimeter: Status and Performance Improvements

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Introduction to Experiment

SLAC $B$-Factory

- Asymmetric energy:
  9.0 GeV $e^-$
  3.1 GeV $e^+$

- Total energy:
  10.58 GeV $\equiv\gamma(4S)$ resonance

- $B^+B^-$ and $B^0\bar{B}^0$ pairs to study $CP$ violation and many other things

Electromagnetic Calorimeter (EMC)

- CsI(Tl) crystals
  - high light yield (50,000γ/MeV)
  - long decay time (940 ns)
- 16 to 17.5 radiation lengths
- 6580 crystals pointing close to interaction point
- Photo diodes and pre-amplifier attached to back of crystal (∼7,300 photo-e⁻/MeV)
- 10-bit ADC + two range bits → 18-bit dynamic range
- Measuring photons from 20 MeV to 8 GeV
- \( \frac{\sigma_E}{E} = 2.3\% / \sqrt[4]{E(\text{GeV})} \oplus 1.35\% \)
  \( \sigma_\theta = \sigma_\phi = 4.16 \text{ mrad} / \sqrt{E(\text{GeV})} \)

SLAC-PUB-10170
Crystal arrangement (barrel & endcap)

Inside barrel

Crystals combined into $7 \times 3$ (or $6 \times 3$) modules

Final barrel

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Performance of Hardware

- Quite stable operation:
  - out of 6580 crystals, only one crystal completely dead
    currently four more dead, but might be recovered
  - 14 more crystals use only one of two diodes
  - some more crystals bad in one energy range, e.g. at low energy
  - from time to time ADC board noisy:
    in worst case masking out until next access

- Electronics regularly calibrated:
  - measuring pedestals
  - known charge injected into pre-amplifiers and read out
    to measure gain and linearity
Calibrations of Individual Crystals

Basics

- Crystals have individual response to energy deposit (overall light yield differences and non-uniformities)
- Light yield decreases due to radiation damage
- Two absolute energy calibrations:
  - liquid source calibration at low energy
  - Bhabha calibration at high energy
- At intermediate energies interpolation linear in $\log E$

Liquid Source System

- Neutron generator surrounded by Fluorinert (FC77)
- $^{19}\text{F} + n \rightarrow ^{16}\text{N} + \alpha$
  $^{16}\text{N} \ (T_{1/2}=7 \text{ seconds})$ decays to $^{16}\text{O} + 6.13 \text{ MeV } \gamma$
- Pipe system transports radioactive liquid past front of crystals
- Detection of $\gamma$ with regular DAQ system
Relative drop in light yield versus time

- Calibration $\sim$ once a month to $\leq 0.5\%$ (syst. uncertainty $0.1\%$)
- Stable turn-key operation

Bhabha Calibration

- Absolute energy calibration with $e^+e^- \rightarrow e^+e^-$ at crystal energies of 2.5 to 8 GeV (depending on polar angle due to boost)
- Requiring most crystals to have $> 200$ direct hits $\implies 0.35\%$ statistical error for each crystal
  systematic error $< 1\%$
- Run off-line up to once a month
- Calibration will soon be automated
- Change in constants similar as change in source calibration constants

![Graph showing time evolution of Bhabha constants](image_url)

- endcap
- forward barrel
- backward barrel
- all

Jan 1, 2003    Jul 1, 2003    Jan 1, 2004    Jul 1, 2004
Cluster Calibrations

Necessary since not all energy captured inside crystals

Cluster Calibration with $\pi^0$ (up to 2 GeV)

- Correct to photon energies based on $\pi^0$ mass peak
- Corrections typically 6 to 8%
- Currently testing an improved version

Cluster Calibration above 2 GeV

- Finding factors for calibration to single-photon Monte Carlo
- Applying same correction factors to data
- Soon using $e^+e^- \rightarrow \mu\mu\gamma$ events for calibration
Recent Improvements in Software

Position of Cluster Inside Crystals

- Depth of cluster inside crystal at 12.5 cm before: cluster center projected to front of crystal
  → improvement in matching clusters and tracks

\[ \Delta \phi = \text{difference in } \phi \text{ angle of cluster position and point where track intersects with calorimeter} \]

\[ \Delta \phi \text{ in rad} = \text{difference in } \phi \text{ angle of cluster position and point where track intersects with calorimeter} \]
Edge Correction

- If photon hits close to edge between two crystals, up to $\sim 3\%$ of energy is lost in gaps
- Dependence on $\theta$ position of crystal
- Module symmetry in $\phi$: $\phi$-dependence folded to just three “crystals”

$\Delta E$ ( = measured $B$ energy minus known beam energy)

Monte Carlo $B^+ \rightarrow K^{*+} \gamma$:

- $\text{FWHM}/2.36 = (45.1 \pm 0.7) \text{ MeV}$ w/out edge corr.
- $\text{FWHM}/2.36 = (42.0 \pm 0.6) \text{ MeV}$ with edge corr.

$\Rightarrow \Delta E$ resolution improved by 7% in this case
Additional Studies and Future Goals

- Many modes to study performance of EMC, e.g.,
  - $e^+e^- \rightarrow \mu\mu\gamma$ events
  - radiative Bhabhas $e^+e^- \rightarrow e^+e^-\gamma$
  - $e^+e^- \rightarrow \gamma\gamma$
  - $D^*^0 \rightarrow D^0\gamma$: $E_\gamma \sim 100 - 400$ MeV
  - $\Sigma_0 \rightarrow \Lambda\gamma$: $E_\gamma \sim 50 - 250$ MeV
- New cluster calibration will soon be implemented
- Bhabha calibration will soon be automated

Conclusion

- BABAR EMC operation stable, performance very good
- Radiation damage measured and calibrated out
- Enhancements made to reconstruction code
- Tweaking calibrations to improve analyses