The BaBar CsI(tl) Calorimeter

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The BaBar Experiment

Goal:

Measure CP violation in B meson decays

How:

Consider B meson decays to CP eigenstate

\[ B^0 \rightarrow f_{CP} \ [e.g. \ J/\psi K_s, \ g^* \pi^-, \ \pi^0 \pi^0] \]

Standard Model explanation of CP violation predicts

Time dependence: \( B^0 \rightarrow f_{CP} \neq \bar{B}^0 \rightarrow f_{CP} \)
Measuring time dependence of $B^o \rightarrow f_{cp}$

Asymmetric collision of $e^+e^-$ at $E_{cm} = Y(4s) \ [10.58 \text{ GeV}]$

$9.0 \text{ GeV} \rightarrow e^- \rightarrow e^+ \rightarrow 3.0 \text{ GeV}$

Produces boosted $B, \bar{B}$ system

$\bar{B} \rightarrow f_{tag} \ [\text{eg. } l\bar{v}X]$

$B \rightarrow f_{cp}$

$\Delta t$

1. Determine flavor of $B$ at $t=0$ with $f_{tag}$
2. Fully reconstruct $f_{cp}$ at time $t$
Reconstruction of $f_{cp}$

Useful $CP$ eigenstates

1. Low branching ratio
2. Often contain $\pi^0$

$$B \rightarrow 3^+ \pi^- \rightarrow \pi^+ \pi^- \pi^0 \rightarrow \delta \delta$$

$\Delta (\pi^0 \rightarrow \delta \delta)$ GeV

$E_\gamma$ (GeV)

Need:
- High efficiency $\gamma$ detection $E_\gamma > 20$ MeV
- Low resolution $20$ MeV $< E_\gamma < 5$ GeV

$\text{CsI(tl) Crystal Calorimeter}$
High Efficiency with Crystal Calorimeter

Need

1. Good Geometric acceptance
2. Very little material in front [reduce conversions] \( \gamma \rightarrow e^+e^- \)

In Cot H Frame

In Lab Frame

9.0 GeV e⁻

(0.23 x0 From tracking and particle id)

3.0 GeV e⁺
Good Resolution - I

\[ E_x = 100 \text{ MeV} \quad E_y = 5 \text{ GeV} \]

\[ \frac{\sigma_E}{E} = \frac{10\%}{\sqrt{E}} \]

- Leakage
- Non-uniformity
- Calibration
- Electronic Noise

\[ \sigma_{\text{leakage}} \]

16 \( x_0 \) \quad 17.5 \( x_0 \)

\[ \sigma_{\text{non-uniformity}} \]

White tyvek wrapping

Printed black lines

Absorbs light to control uniformity

\[ < 1 \text{ } 0\% \]

\[ < 0.5 \text{ } 0\% \]
Good Resolution - II

\[
\frac{\sigma_E}{E} = \frac{10^0}{1E} + \sigma_{\text{leakage}} + \sigma_{\text{non-uniformity}} (0.5\%) + \sigma_{\text{calibration}} + \sigma_{\text{electronic noise}}
\]

**Electrical Noise**

- Low noise pre-amp [full custom ASIC]
- 2μS

- Large area silicon PIN diodes epoxied to Xstal
  [High quantum efficiency - well matched to CsI emission]

**PROBLEM:** Large background flux of γ from machine
[1 per crystal per 20μS of 1 keV]

⇒ 1) Make shorter pulse length
2) Full waveform digitization and signal processing [DSP]

\[ \sigma < 150 \text{ keV} \] negligible ambiention to \( \frac{\sigma}{E} \)
Calibration

- Large machine backgrounds may cause significant radiation damage
- Light output of crystal is reduced
- Essential to calibrate out this light loss

Novel source calibration under investigation

Activated Halocarbon oil

\[ ^{16}_0 \rightarrow ^{16}O + \gamma (6.3 \text{ MeV}) \]
\[ \tau_{1/2} = 7 \text{ sec} \]

In situ bhabhas + source \( O_{\text{calibration}} < 0.25\% \)
Radiation Hardness

- Machine backgrounds $\sim 90$ rad/yr
- Maybe higher during injection and startup
- Ongoing program to understand damage mechanisms and improve radiation hardness

- Damage believed to be formation of colour centres due to impurities $\Rightarrow$ remove impurities

![Graph showing light yield vs. integrated dose (Rads)](image)
- 6662 Crystals from 5 different vendors
- Delivered from June 1996 to Jan 1998
- Total cost of salt + crystal growth $\approx 14$ M
Construction - Module assembly

7x3 crystals per module

Crystals + front-end readout in carbon fibre boxes

Aluminum strong back

Modules supported by cylindrical strongback

Installation complete early 1999
Testbeam Results

- Testbeam done with $6 \times 6$ crystal array
- Incomplete electronics and early version of front-end readout
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[target performance equation]

- Close to target performance
- Final electronics and readout should meet goal
Conclusions

- Measurement of CP violation in B mesons requires highly efficient $\pi^0$ reconstruction
- CsI(Tl) is required technology
- Detector optimized for excellent resolution of $\pi$ in asymmetric $e^+e^-$ environment
- Construction complete in early 1999