A Systematic Study of Radiation Damage to Large Crystals of CsI(Tl) in the BaBar Detector

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• Energy resolution for the detection of photons from $\pi^0$ in the range from 20 MeV to 4 GeV:

$$\frac{\sigma_E}{E} = \frac{(2.30 \pm 0.03 \pm 0.3)\%}{\sqrt[4]{E(GeV)}} \oplus (1.35 \pm 0.08 \pm 0.2)\%$$

• The energy term comes from: fluctuations in photon statistics, electronic noise and beam background

• Original MC studies predicted that the constant term arises from non-uniformity in light collection ($\leq 0.5\%$), front and rear shower leakage ($\leq 1\%$) and uncertainties in calibration (0.25%) totaling 1.2\%
GEANT simulation of untapered, 35cm long crystal with large lateral dimensions (40x40cm) resulted in well-known acceptance envelope.
Crystal Response Uniformity

Uniformity is influenced by:

- crystal clarity
- surface finish
- wrapping
- radiation damage of the front of the crystal (?)

Require less than 0.5% contribution to $\sigma_E/E$ for up to 5 GeV.

Define SLOPE to be drop across the full length of the crystal back to front:

- negative: back (PD/PMT) higher than front
- positive: front higher than back
Crystal Scanner Test

- Use **16 spare full size crystals**
- Closely model exposure of the crystals in BaBar
- Irradiation with 1.173 and 1.333 MeV photons from $^{60}\text{Co}$ source (1-2 Rad/h)
- **In-situ measurement** of the change of the light yield along length of crystals gives tight control of systematics

**Goal:** Develop a correction function to model crystal response to irradiation to be used in MC simulation
Scanner Setup
Data Taking

- Data points are taken every 2cm along the length of the crystal
- Each data point takes 5 min
- 12h for a scan of 16 crystals starting 6h after irradiation
- Use Novosibirsk+Exp background (6 parameters) for the signal fit
- Double the dose until reaching 6000 Rad

![Graph showing ADC counts for isotopes $^{60}$Co, 1.173 & 1.333 MeV and $^{88}$Y, 1.8 MeV.](image)
Negatively Sloped Crystal (BCAL0204)

LY change with Irradiation

Back Front Back Front
Positively Sloped Crystal (BCAL4999)

LY change with Irradiation

Back

Front

Back

Front

Normalized LY
Dose Dependence of Uniformity Change

- LY decreases more at the irradiated end
- Dependence of the non-uniformity change slope on the log_{10}Dose is linear or quadratic
- The drop is higher for crystals with originally positive slope
Measured Results

Extrapolation

<table>
<thead>
<tr>
<th>Crystal #</th>
<th>Slope, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 kRad</td>
<td>1.49±0.10%</td>
</tr>
<tr>
<td>1 kRad</td>
<td>1.66±0.11%</td>
</tr>
<tr>
<td>10 kRad</td>
<td>2.56±0.14%</td>
</tr>
</tbody>
</table>
Non-Uniformity of EMC crystals

Average LY drop over the length of EMC crystal -6.6% for PD and ~-3% for the PMT.
MC Study

- Generate single γs of 0.1, 0.5, 1 & 5 GeV going into |cosθ|<0.2
- Non-Uniformity implemented as weights on 8 sections over the length of the crystal
- Distributions look similar up to 1 GeV: flat at ±2%
- 5 GeV non-uniformity compensates/enhances rear leakage
Non-Uniformity Contribution (MC)

- For $\gamma$s of 0.1 GeV allowed slope $\pm 2\%$
- For $\gamma$s of $>0.5$ GeV allowed slope $-5\%$ to $+2\%$
  - MC: $\pm 5\%$ slope non-uniformity contributes 1% to $\sigma_E/E$
  - Target: 0.5%
  - Data 2001: constant term in $\sigma_E/E$ agrees with original MC prediction
Outlook

• Need to understand how the measured non-uniformity will affect resolution
• Measure same crystals with PD, check if PMT/PD correction function stays the same
• Study more crystals? Different vendors?