Calibration and Reconstruction Performances of the KLOE Electromagnetic Calorimeter

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Outline

• The KLOE experiment and the EMC design
• Reconstruction and calibration of energy
• Reconstruction and calibration of timing
• Performances on simple physics examples
The KLOE goal is to measure $\text{Re}(\varepsilon'/\varepsilon)$ to $\sim 10^{-4}$
KLOE CALORIMETER REQUIREMENTS

- Reconstruct $K_S, K_L \rightarrow \pi^0\pi^0$ vertices with $\sim 1\text{cm}$ resolution
- Discriminate $K_L \rightarrow \pi^0\pi^0$ from $K_L \rightarrow \pi^0\pi^0\pi^0$
- Fast for triggering and Bhabha background rejection
- Provide useful information for particle identification ($K_{\mu3}$ rejection)

- $\sigma(E)/E \sim 5\% /\sqrt{E}(\text{GeV})$
- High efficiency $20 < E_\gamma < 300 \text{ MeV}$
- $\sigma(t) \sim 70 \text{ ps} / \sqrt{E} \text{ (GeV)}$
- $\sigma_{x,y,z} \sim 1 \text{ cm}$ for photon conversion point
- Hermeticity
THE CALORIMETER STRUCTURE

Fine sampling lead/scintillating fibers calorimeter
- Volume Ratio Fiber:Lead 50:50
- Energy sampling fraction 13%
- $X_0 = 1.6 \text{ cm } \rho = 5.3 \text{ g/cm}^3$

• 24 barrel modules: 4.3m length
  60 cells (5 layers) – 4.4×4.4 cm² granul.
• 2 × 32 endcap modules 10/15/30 cells
• 4880 read-out channels

Fiber choice: Kuraray SCSF-81 and Pol.Hi.Tech 0046
PM choice: Mesh Hamamatsu R5946 1.5”
• Online filter selects 100 Hz of golden mips in the whole detector

• Peak of the ADC spectrum = response at calorimeter center (MIP)
  (~1 day data taking → 1000 events/cell  →  1÷2 % stat. accuracy)

• The attenuation curve is measured for each channel and used in the reconstruction procedure 
  \( w(z) = A e^{-z/\lambda_1} + (1-A) e^{-z/\lambda_2} \)
ENERGY CALIBRATION with E.M. SHOWERS

- Bhabha events for cell cross-calibration
- $e^+e^- \rightarrow \gamma\gamma$ to set the absolute energy scale
- Automatic procedure: every $100 \text{ nb}^{-1}$

Before ................. After Calibration

$\gamma\gamma$ on BARREL

$\gamma\gamma$ on EndCaps
LINEARITY IN ENERGY RESPONSE AND ENERGY RESOLUTION

- Average energy scale: 38 MeV/MIP
- Using the number of p.e./MIP measured at cosmic test:
  light yield ~1 p.e./MeV per side @ calorimeter center
- A factor of 2 more light near the PMs
- Energy resolution dominated by sampling fluctuations
- No cuts have been made on “holes” or specific detector regions

\[ \text{\(e^+e^ {-}\rightarrow e^+e^ {-}\gamma\)}\]

\[ \left(\frac{E_{\gamma}}{E}\right) = 5.7\% / \sqrt{E_{\text{GeV}}} \pm 0.6\% \]
Mass reconstruction within 1% with PDG. Resolutions are in good agreement with MC expectation.

EXAMPLES OF MASS RECONSTRUCTION

\[ M_\pi = 135 \text{ MeV} \]
\[ \sigma_\pi = 14 \text{ MeV} \]

\[ M_\eta = 546 \text{ MeV} \]
\[ \sigma_\eta = 42 \text{ MeV} \]

\[ K_S \rightarrow \pi^0 \pi^0 \]
\[ M_K = 494 \text{ MeV} \]
\[ \sigma_K = 27 \text{ MeV} \]

\[ 3\gamma \text{ events: } \phi \rightarrow \eta \gamma, \pi^0 \gamma \]

\[ \pi^0 \rightarrow \gamma \gamma \]
from \[ \phi \rightarrow \pi^+ \pi^- \pi^0 \]
TIMING CALIBRATION WITH COSMIC RAYS

- Select straight cosmosics (high $|p|$)
- 5+5 time measurements of known track length $L$
- Fit $t$-$L$ relation; $t^0 = t^0_A + t^0_B$ time offsets obtained through iterative minimization of fit residuals

$v_{\text{eff}}$ from the width

$\Delta t^0 = t^0_A - t^0_B$ is the center

t = L/c

calorimeter

$\Delta t^0 = t^0_A - t^0_B$ (ns)

Residuals (ns)

Channel Number
for a MIP in a cell (~38MeV) : \( \sigma(t) \sim 340 \text{ ps} \) corresponding to: \( \sigma(t) \sim 64 \text{ ps}/\sqrt{E(\text{GeV})} \)
Each 100 nb\(^{-1}\) the \(t^0\)\'s in all columns are recalibrated using \(e^+e^- \rightarrow \gamma\gamma\) to improve their determination.

**Time spectra with**

\[ e^+e^- \rightarrow \gamma\gamma \]
Comparing the difference of timing between $\gamma\gamma$ events at small and large angle we estimate that of the 147 ps of constant term:

- 50 ps mis-calibration
- 55 ps bunch spread
- 120 ps machine time spread

\[ \sigma_T = 54 \text{ ps/}(E/\text{GeV}) + 147 \text{ ps} \]
Clean signature (late neutral cluster) is used for $K_S$ tag

Reconstruction of $\beta^*$ depends on the $\phi$ boost. Its width measures the machine energy spread 
$\delta E_{\phi} \sim 1 \text{ MeV} \Rightarrow \delta \beta^* \sim 0.004$
For $K_L \rightarrow \pi^+ \pi^- \pi^0$, residuals not expected to differ from $K_L \rightarrow \pi^0 \pi^0 \pi^0$ but resolution is worse:

### Table

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<thead>
<tr>
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<th>$K_L \rightarrow \pi^+ \pi^- \pi^0$</th>
<th>$K_L \rightarrow \pi^0 \pi^0 \pi^0$</th>
<th>$K^\pm \rightarrow \pi^\pm \pi^0$</th>
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<tbody>
<tr>
<td>$N_{\gamma}$</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>$E_{\gamma}$</td>
<td>60—80 MeV</td>
<td>100—120 MeV</td>
<td>100—120 MeV</td>
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CONCLUSIONS AND OUTLOOK

• The KLOE Calorimeter has been kept in operation as a whole apparatus for more than 2.5 years in good operating conditions → (the number of dead channels always below 0.1% and overall good detector stability)

• The calibration procedures of energy and timing are working.

• Energy resolution of $5.7\% / \sqrt{E/\text{GeV}}$ measured

• Timing resolution of $54\text{ ps} / \sqrt{E/\text{GeV}} \oplus 50\text{ ps}$ achieved

• Good calibration stability observed in 6 months of operation.

• Reconstruction of masses and neutral vertices satisfactory

• Work is in progress to:

  1) complete the setting of the time scale

  2) correct the residual response non-linearity and the response along cracks regions

  3) make fully automatic the calibration procedures