MC simulation of LXe detector

(presented by)

Giovanni Signorelli

INFN sez. di Pisa and Scuola Normale Superiore di Pisa
• The simulation of the calorimeter is embedded in the GEANT 3 simulation of the full detector
• All major characteristics of all sub-detectors are included
• Many kinds of events can be generated

<table>
<thead>
<tr>
<th>Type of event</th>
<th>ITYPE Code</th>
<th>Routine</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e^+$ - gamma signal</td>
<td>1</td>
<td>EVESIG</td>
</tr>
<tr>
<td>$e^+$ - gamma radiative decay</td>
<td>2</td>
<td>EVERDE</td>
</tr>
<tr>
<td>$e^+$ - gamma accidental background; 1st kind</td>
<td>3</td>
<td>EVEACC</td>
</tr>
<tr>
<td>$e^+$ - gamma accidental background; 2nd kind</td>
<td>4</td>
<td>EVEACC</td>
</tr>
</tbody>
</table>

[...]

• A simulation of the Large Prototype exists

(http://meg.psi.ch/subprojects/pisamc/doc/doc.html)
An example of the $\mu \rightarrow e \gamma$ decay
MC simulation of the LXe calorimeter

Interaction point 
\( \theta, \phi, z, t \)

Energy deposit \( E \)
There exist at present two simulation codes which agree

**Proposed detector**

- $0.8 \text{ m}^3$
- 848 PMTs (312 FF)
- $65 < r < 112 \text{ cm}$
- $|\cos \theta| < 0.35$
- $|\phi| < 60^\circ$

- PMT coverage as high as possible on the FRONT FACE
- Complete material simulation (efficiency)
A view of all 848 photomultipliers

Coverage ~ 30 %  ⇒ PMT positions not definitive
It is necessary to understand the basic characteristics of a 52.8 MeV photon shower in LXe

• GEANT 3.21 and tracked secondaries down to 10 keV

• Properties of LXe:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>3 g/cm³</td>
</tr>
<tr>
<td>Light yield</td>
<td>42,000 ph/MeV</td>
</tr>
<tr>
<td>$\lambda_{Rayleigh}$</td>
<td>30 cm (variable)</td>
</tr>
<tr>
<td>$\lambda_{Absorption}$</td>
<td>100 cm (variable)</td>
</tr>
<tr>
<td>$X_0$</td>
<td>2.77 cm</td>
</tr>
</tbody>
</table>

• PMT characteristics

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius</td>
<td>2.54 cm</td>
</tr>
<tr>
<td>Window</td>
<td>fused silica</td>
</tr>
<tr>
<td>Q.E.</td>
<td>10% → 5%</td>
</tr>
</tbody>
</table>
What are the main characteristics of the simulated showers in LXe?

Average over 1,000,000 events

- Relative to conversion point
- Longitudinal spread ~ 5 cm
- Max energy deposit after 1 cm

- Lateral spread ~ 1 – 2 cm
- Relative to conversion point
Energy deposited in LXe by a 52.8 MeV $\gamma$

despite those mean properties…
…There are large fluctuations
Distribution of \((x_{\text{interaction}} - x_{\text{Center of Energy}})\) MC

\[\sigma \approx 1 \text{ cm!}\]
Position reconstruction
We want $x_{int}$ not $x_{CoE}$

⇒ Use the information of the FRONT FACE

1st method: Weighted average (bias)

• Use only PMT in a circle and iterate
Position resolution as a function of the photon hit position

\[ dn = \rho \, dx \, dy \quad \rightarrow \quad dn = 2\pi \rho \, r \, dr \]
Nice reconstruction but tends to “collapse” on certain points

\[ x_{\text{int}} \text{ (cm)} \]

\[ x_{\text{cir}} \text{ (cm)} \]

\[ \sim 10\% \text{ of the photons interact before reaching the xenon} \]
All results shown are obtained shooting a 52.8 MeV photon normally on a 2 x 2 PMT window, uniformly.

Results of **CIRCLE AVERAGE**:

Which corresponds to an angular resolution of 8.3 mrad.
2\textsuperscript{nd} method:

- Fit of the expected-observed light from a point-like source
- $Q_{exp} \propto$ solid angle

\[ \chi^2 = 2 \sum_{i=1}^{N} \left( \frac{Q_{exp}^i - Q_{meas}^i}{Q_{exp}^i + Q_{meas}^i} \right)^2 \]

- Works also with missing/broken PMTs
Results of **FRONT FIT**:

Angular resolution = 8.1 mrad (sigma)

(Slightly different from the previous note because of different Q.E.)
The fit reconstruction has a better behaviour (though not perfect)
Result of the **FRONT FIT** on a **CIRCLE**:

Angular resolution = **7.5** mrad (sigma)

(z constant from FRONT FIT)
The resolution is limited by

1. Shower fluctuations
2. PMT dimensions

In fact:

1. Pointlike source and 2’’ PMTs
   \[\Rightarrow 1.0 \text{ mm sigma} \quad (1.5 \text{ mrad})\]
2. Real event and 1’’ PMTs
   \[\Rightarrow 3.5 \text{ mm sigma} \quad (5.4 \text{ mrad})\]
From the FRONT FIT one gets also the depth (z-coordinate) of the conversion point.

Corresponding to ~ 85 psec intrinsic FWHM
Converted before xenon
Rough evaluation of timing performance

Minimum time on the front face corrected with the reconstructed $z$

$t_{\text{min}}$

$Z_{\text{fit}}$

$\chi^2/\text{ndf} = 130.9 / 46$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>$593.3 \pm 11.22$</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>$0.6472E-03 \pm 0.9425E-03$</td>
<td></td>
</tr>
<tr>
<td>Sigma</td>
<td>$0.6545E-01 \pm 0.7956E-03$</td>
<td></td>
</tr>
</tbody>
</table>

$\sim 150$ ps FWHM but uses only one PMT
Energy reconstruction
• The *ideal* case is simple:

\[ E \propto \sum_i Q_i w_i = Q_{\text{sum}} \]

\[ w_i = \text{density of PMTs on various faces} \]

\[ \sim 2.5 \% \text{ FWHM} \]

• Physics effects \( (\lambda_{\text{Ray}}<\infty, \lambda_{\text{Abs}}<\infty) \) worsen the energy resolution:

![Graph showing ideal, diffusion, absorption, and diffusion plus absorption effects on collected charge with FWHM indicated.](image_url)
Energy resolution using $Q_{\text{sum}}$ worsens rapidly with increasing absorption (not corrected for $z_{\text{int}}$).

$\Rightarrow$ We need different algorithms to guarantee a good resolution in presence of absorption.
Dipole model

Shower = “CoE”

“conversion”

Two lamps of relative position and intensity fixed, to mimic the true shower.

• MINUIT reconstruction
• \((\theta, \phi) \sim 10\) mrad
• Better than \(Q_{\text{sum}}\) at small \(\lambda_{\text{Abs}}\)

• FWHM 8% for \(\lambda_{\text{Abs}} 50\)
  6.5% for \(\lambda_{\text{Abs}} 300\) cm
Principal component analysis

- A vector of parameters \( \{p_i\} = E, \theta, \varphi, z \ldots \)
- A vector of observables \( \{q_j\} = \text{PMT charges} \)

\[ \{q_j\} \rightarrow \{p_i\} \]
All in a linearised way ⇒ fast

**Linearisation**

Here are the formulas:

\[ p_i = w_{ij} (q_j - q_j^0) + c_i \]

Generate a sample of MC events and **find the best hyper-plane**:

Minimize (analytically) the deviation between the linear approximation and the true \( p_i \) values **(ONCE AND FOR ALL)**

\[ q_j^0 = \frac{1}{N_{\text{events}}} \sum_{N_{\text{events}}} q_j \]

\[ M_{kl} = \langle (q_k - \bar{q}_k) (q_l - \bar{q}_l) \rangle \]  
**Covariance matrix**

\[ w_{ij} = \frac{M^{-1}}{N-1} \left[ \sum_{\text{events}} p_i q_j - \frac{1}{N_{\text{events}}} \sum_{\text{events}} p_i \sum_{\text{events}} q_j \right] \]  
**Analytical**

\[ c_i = \langle p_i \rangle - \langle w_{ij} q_j \rangle \]  
**Average on MC events**

Giovanni Signorelli
Algorithms details: CERN EP 81-12/ReV

CDF/DOC/TRIGGER/PUBLIC/3108

SVT
Silicon Vertex Tracker

TECHNICAL
DESIGN REPORT
Version 2.1 – November 22, 1994

The following people have contributed to the development of the SVT Project and to the writing of this document:


INFN - Pisa
Results for energy:

- $\lambda_{\text{Ray}} = 30 \text{ cm}$
- $\lambda_{\text{Abs}} = 100 \text{ cm}$
- One set of constants for all the detector

\[
\left. \frac{\Delta E}{E} \right|_{52.8 \text{ MeV}} = 4.8\% 
\]
Knowing the interaction point (from INNER FIT)

Different set of constants:

square of $5-\sigma$ edge around the reconstructed position

\[
\lambda_{\text{Abs}} = 100
\]
Longitudinal energy loss

\[ \lambda_{\text{Abs}} = 100 \]
Background reconstruction:

- Radiative decay
- Constants computed using signal events

$\lambda_{Abs} = 100$
Absorption dependence
Expected Performance

- Detector Efficiency

<table>
<thead>
<tr>
<th>Detector</th>
<th>Radiation thickness $X_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet</td>
<td></td>
</tr>
<tr>
<td>Coil</td>
<td>0.153</td>
</tr>
<tr>
<td>Cryostat</td>
<td>0.048</td>
</tr>
<tr>
<td>Photon Detector</td>
<td></td>
</tr>
<tr>
<td>Outer wall Honeycomb PMT+holder</td>
<td>0.068</td>
</tr>
<tr>
<td></td>
<td>0.21</td>
</tr>
<tr>
<td>Total</td>
<td>0.482</td>
</tr>
</tbody>
</table>

- 74% with ±4% energy cut
- Reconstruction efficiency is not know yet.
- A possible inefficiency may result from gamma conversions very close to the PMT surface.
SUMMARY

• A MC simulation of the final calorimeter is embedded in the simulation of the complete detector

• We studied $\gamma$ shower in LXe

• The position can be reconstructed on the whole detector with a resolution

  $\text{FWHM} \sim 4/5\text{mm} \ - \ 6/7.5 \text{ mrad}$

• The energy can be reconstructed on the whole detector with a resolution

  $\text{FWHM} \sim 4 \%$

(Conservative values, $\lambda_{\text{abs}} = 1 \text{ m}, \text{QE}=5\%$)
End of presentation
Bias on $x_{\text{ave}}$
MuXeC