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PSI, February 2003
MEG internal meeting
Outline

• **MC:**
  – shape-QE studies summary
  – pile up in LXe

• **LP data analysis:**
  – gain/QE/$\lambda_{\text{Abs}}$/\$\lambda_{\text{Ray}}$
  – Radioactive Background
  – Timing resolution
  – $V_{\text{light}}^{-n}$
  – Liquid Xe level
Monte Carlo

- QE - shape
- Pile-up
- segmentation
An example of $\mu \rightarrow e \gamma$ decay
Event Generation: MEGEVE

Pair events:
- Signal: $\mu \rightarrow e\gamma$
- Radiative decay (correlated bck)
- Michel positron + $\gamma$-bck

Positron only events:
- Signal positron
- Michel positron

Gamma only events:
- Signal $\gamma$
- $\gamma$ with flat spectrum
- Bck: $\gamma$ from radiative decay or annihilation in flight
Simulation of LXe calorimeter

Blu: external vessel (Al)

Yellow: honeycomb support (plastic)

Red: PMTs (glass mixture)
- 0.8 m³
- 848 PMTs (312 FF)
- 65 < r < 112 cm
- \(|\cos \theta| < 0.35\)
- \(|\phi| < 60^\circ\)

Maximum PMT density on Inner Face (FF)
\( \gamma \) interaction in Lxe.

- Scintillation photons are traced inside the liquid Xenon and followed until they reach the PMTs.
- Absorption and diffusion may occur.

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

Energy deposit \( E \)
**LiXe energy resolution**

**QE studies:**

<table>
<thead>
<tr>
<th>QE</th>
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**Shape studies:**

Compare LiXe and a VLP (100 x 50 x 50 cm$^3$) to check the effects of a different geometry on position and energy resolution.

• no difference with the curved detector for position resolution (10.6 mm FWHM in both cases for a realistic situation); a 3% systematic correction is needed on both coordinates for VLP

• slight improvement in energy resolution (from 4% to 3.5%);

• however, more critical problems of energy containment

**a much larger volume (1.5 m$^3$) of Xenon would be needed (and PMTs!).**
LiXe energy resolution

QE studies:

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- Ineffective for short (1 m) absorption length
- Important for timing resolution (see later on…)

Shape studies:
Curved vs BOX (100 x 50 x 50 cm$^3$): different geometry on position and energy resolution.

- **position resolution**: no difference. (10.6 mm FWHM)
  - a 3% systematic correction is needed on both coordinates for VLP

- **energy resolution**: slight improvement (from 4% to 3.5%);

- **energy containment**: more critical problem

  a much larger volume (1.5 m$^3$) of Xenon would be needed (and PMTs!).
Position evaluation

- weighted average of PMT charge (bias);
- PMT with the maximum charge only (trigger);
- MINUIT fit on all PMTs;
- MINUIT fit on the Inner Face only;
- MINUIT fit on a circle around the PMT with the maximum charge;
- MINUIT fit on a circle around the PMT with the maximum charge (improved).

Best results with the fifth method:

\[ \sigma_x \approx \sigma_y \approx 5 \text{ mm} \]
Energy evaluation

Energy reconstruction requires more sophisticated algorithms than a simple “sum of charges” ($Q_{\text{sum}}$).

Two methods:

- **full MINUIT fit** on expected vs measured charge on all PMTs:

\[
Q_{\text{expected}} = \frac{\text{const} \, E \exp \left( - \frac{r_{\text{eff}}}{\lambda} \right)}{r^2} \Delta \Omega
\]

$\Delta \Omega$ = PMT solid angle as seen from the interaction point;

$r_{\text{eff}}$ = effective path in LXe for taking into account diffusion.

It requires a shower model (dipole) and long time.
principal component analysis:

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

\( \{q_j\} \rightarrow \{p_i\} \)
Energy resolution comparison

- Absorption length = 1 m, various positions
- linear fit (PCA)

VLP: 3.5 %
Curved detector: 4 %
Energy escape (LiXe)

Cos $70^0 = 0.34$

The fiducial region:

- $-60 < \varphi < 60$
- $|\cos \theta| < 0.35$

looks ok!
Energy escape from VLP

Significant energy losses also rather close to the center.
No bias needed for position reconstruction in proposed detector!
Energy resolution vs. absorption

\[ \frac{\Delta E}{E} < 4\% \text{ for } \lambda_{\text{Abs}} > 1 \text{ m} \]

(linear fit, PCA)
\( \lambda_{\text{Abs}} \) for last test

Observed/Expected light vs distance

\[ \chi^2/\text{ndf} \, 16.72 / 40 \]

- Constant: \(-0.3552 \pm 0.2891\)
- Slope: \(-0.1970 \times 10^{-2} \pm 0.7971 \times 10^{-2}\)

\( \lambda_{\text{Att.}} > 1 \, \text{m} \)
Segmentation

- 6 layers of PMTs inserted at –30, 0, and 30 degrees
  - PMTs are placed on all walls with maximum density to keep the homogeneity same in both segmented and non-segmented cases.
  - Resolution is estimated by using simple Qsum
- We can observe more pe in case of short $\lambda_{abs}$
  - $\lambda_{abs}=1m$: resolution 15.4% $\rightarrow$ 11%
- We lose efficiency due to the dead volume occupied by inserted layers of PMTs in any case.
- In case of long $\lambda_{abs}$, energy leakage in the PMT layers cause deterioration of resolution in addition to the efficiency loss.

<table>
<thead>
<tr>
<th>$\lambda_{abs}$</th>
<th>non-segmented</th>
<th>segmented</th>
<th>Eff loss(relative)</th>
</tr>
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<tr>
<td>1m</td>
<td>15.4%</td>
<td>9.7%</td>
<td>11%</td>
</tr>
<tr>
<td>5m</td>
<td>3.7%</td>
<td>3.7%</td>
<td>28%</td>
</tr>
<tr>
<td>$\infty$</td>
<td>1.5%</td>
<td>2.0%</td>
<td>44%</td>
</tr>
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Segmentation[2]
Reflector

- Reflector does not help to reduce the path length of scintillation light.
- Reflection efficiency (< 100%) can cause nonuniformity.

\[ \lambda_{\text{Ray}} = 30 \text{cm} \]
Ref eff = 100%
No absorption
Reflector[2]
Pile-up and sensitivity

In the 90% acceptance window

**Prompt background:**

\[3 \div 4 \times 10^{-15} \text{ per } \mu^+ \text{ decay}\]

**Accidental background:**

\[2.2 \div 3.5 \times 10^{-14} \text{ per } \mu^+ \text{ decay}\]

\[\mu \rightarrow e + \nu + \nu + \gamma \]

\[e^+ e^- \rightarrow \gamma \gamma\]

Besides these high energy photons...

And S.E.S. \(3.6 \div 5.6 \times 10^{-14}\)

\(2 \div 3 \times 10^7 \mu^+ / \text{sec}\)
FULL SIM of pile up in LXe

There is a **180 kHz** rate of photons with **E>0.5 MeV** due to $\mu \rightarrow e + \nu + \nu + \gamma$

FULL SIMULATION!

How often an accidental superposition of **two** background events gives a signal in the 90% acceptance window around 52 MeV?

1 intrusion every 50 gates 100 ns wide

With this proportion add the signals PMT by PMT

Perform the energy reconstruction

+ 5% events in the signal region

Made use of no topological cut (clusters, electron, pulse shape....)
Reconstruction of bkg events

$\gamma$’s from radiative decay; set of constants computed using signal events.

A small bias, but very small spill-in of background in the signal region.
FULL SIM of pile up in LXe

There is a **180 kHz** rate of photons with \( E > 0.5 \text{ MeV} \) due to \( \mu \rightarrow e + \nu + \nu \gamma \)

How often an accidental superposition of **two** background events gives a signal in the 90% acceptance window around 52 MeV?

1 intrusion every 50 gates 100 ns wide

With this proportion add the signals PMT by PMT

Perform the energy reconstruction

10 % increase in the acceptance window for the radiative fraction
2.5 % increase in the acceptance window for the annihilation-in-flight fraction

+ 5% events in the signal region

**Made use of no topological cut (clusters, electron, pulse shape....)**
MC conclusion

• High absorption length $\Rightarrow$ curved shape is ok.
• QE improvement welcome (see timing resolution…)
• (accidental)$^2$ background not harmful
MC for QE measurement?

- Use the 4 alpha-sources inside the Large Prototype and compare data and MC with NO ABSORPTION (⇒ need to use Gxe @ 170 K)

- The method depends very much on the details of the simulation (reflection on the PMT window and on walls….)
  - we excluded PMTs on the alpha face but only three points left
  - Need for a dedicated test station to measure all QE
PMT characterization

- FULL DESIGN AND MECHANICAL DRAWINGS COMPLETED

- CALL FOR TENDERS MADE AND JOB ASSIGNED TO THE COMPANY CINEL-Vigonza (PD), Italy

- CRYOSTAT DELIVERY EXPECTED BY THE END OF FEBRUARY

- ORDERS MADE FOR DRY UHV PUMPING GROUP, LEAK DETECTOR, UHV COMPONENTS, CRYOGENIC BOTTLE, PMT’s …

- LABORATORY PREPARATION UNDER WAY

- FOR MORE INFORMATION ASK FRANCO
Data

• With $\alpha$
• With $\alpha$ runs
• With electrons
• ....
Xenon Calorimeter Prototype

• Tests on the LXe calorimeter are currently under way in KEK Japan using a “LARGE PROTOTYPE”:
  • 40 x 40 x 50 cm³
  • 264 PMTs, 100 litres Lxe

• Used for the measurement of:
  • Test of cryogenic and long term operation
  • Energy resolution (expected 1.4 – 2 %)
  • Position resolution (few mm)
  • Timing resolution (100 ps)

• Measurement done with:
  • Cosmic rays
  • 40 MeV γ from Compton Backscattering
  • α-sources
  • electron beam (@ KSR)
The LP from “inside”

α-sources and LEDs used for PMT calibrations and monitoring
QE measurement

• Use the 4 alpha-sources inside the Large Prototype and compare data and MC with NO ABSORPTION (⇒ need to use Gxe @ 170 K)

• The method depends very much on the details of the simulation (reflection on the PMT window and on walls….)
  • we excluded PMTs on the alpha face but only three points left
  • Need for a dedicated test station to measure all QE
QE: better go $5 \times 10^6$

- Due to the higher $W_{ph}$ for Gas Xenon the alpha signal in gas used to be cut

The old quantum efficiencies were slightly over-estimated
Purity and other $\alpha$ uses

Alpha source: measured/expected light as a function of the $\alpha$-PMT distance

Present...

Cfr. May test

$\lambda_{\text{Att.}}>1$ m

Alpha source measurements: essential for purity monitor and physics measurements ($n, \lambda_{\text{Rayleigh}}, \ldots$)
Diffusion length \( (\lambda_{\text{Rayleigh}}) \)

- Ratio of the charge collected on the face containing the alpha source to the total collected charge
- Independent of the absorption

\[ \lambda_{\text{Ray}} \approx 70 \text{ cm} \]

Still some systematics to be studied depending on the MC (reflections on PMT windows and LP material…)

In Gxe consistent with \( \lambda_{\text{Ray}} = \infty \)
Radioactive background w/LP

• **α-trigger** with $5 \times 10^6$ gain

• Geometrical cuts to exclude α-sources

• **Energy scale:** α-source
  - $^{208}$Tl (2.59±0.06) MeV
  - $^{40}$K (1.42 ± 0.06) MeV
  - $^{214}$Bi $^{208}$Tl ??

• uniform on the front face

• few 10 min (with non-dedicated trigger)

• **nice calibration** for low energy γ’s

• Seen for the first time! Studies are going on:
  spatial distribution of background inside the detector
Timing resolution test

\[ \sigma_t = (\sigma_z^2 + \sigma_{sc}^2)^{1/2} = (80^2 + 60^2)^{1/2} \text{ ps} = 100 \text{ ps (FWHM)} \]

- Time-jitter due to photon interaction
- Scintillation time, photon statistics

Measurement of \( \sigma_{sc}^2 \) \( \Rightarrow \) electron beam

Use of Kyoto Syncrotron Ring (KSR) @ 60 MeV (2/12/02 \( \rightarrow \) 6/12/02)
Timing resolution

- 60 MeV $e^-$→ material degradation → only 128 channels (out of 228) had the TDC
- We estimate the *intrinsic* timing resolution vs p.e.
- Divide PMTs in two groups: $\sigma_{sc} = \text{RMS}[\frac{1}{2}(T_L-T_R)]$ at center
- $T_{L,R} =$ weighted average of the PMT TDCs (time-walk corrected)
• A factor of 10 in number of photo-electrons w.r.t. the Small Prototype

• Analysis still in progress: position-dependent corrections and cross talk problems
Resolution (preliminary)

$\sigma_{sc} = 200\ \text{ps (FWHM)}$

$\sigma = 87\ \text{ps}$

Still to be done:

- event filtering
- full event reconstruction

(need to account for position correction)
Cross-talk care

10 ns delay cables added to increase the phase of discriminator input pairs

Problems fixed only with 19 over 64 pairs
Using the correlation between the fitted coordinates of the “center” of the shower and the difference in arrival times on the various LP faces one can estimate $v_{\text{light}}$ and $n$ for Xenon.

$n \approx 1.7$

• Need to refine the technique

• Understand via MC what is the meaning of “center of shower” and $T_{L,R}$,...
Data conclusion

- $\alpha$ runs are essential for monitoring
- Xenon is pure!
- The timing resolution is consistent with the expectations but needs to be checked
Is LP completely full of LXe?

1st clue: the top-source peak is higher in Lxe but not in GXe

The source somehow gets more distant from the wall! (5 mm)
2nd clue: central spot:

- a) gives a lower peak at correct $z$
B) easy explanation for its position
Face Q ratio

- $R^{-1} = \text{Charge of the face with alpha/Charge on opposite face}$

- $R$ is different for LIQUID and GAS because of Rayleigh scattering

- $R_{\text{liquid}} \approx 1\quad R_{\text{Gas}} \approx 3$
Time Evolution

Run 4476

Run 4596
Data conclusion

- $\alpha$ runs are essential for monitoring
- Xenon is pure!
- The timing resolution is consistent with the expectations but needs to be checked
End
Background distribution

![Image of two scatter plots showing distribution in x_avg and y_avg (cm).]
Selection in $z$

$\sigma^2$ is the rms of the front face charge distribution
Predicted $^{208}$Tl position

- Tl peak slightly below $\alpha$-peak
- Take the difference in light-yield between $\alpha$ and $\gamma$ (20 %)
Is the LP full of Xenon?

GXe

LXe
**Clues**

- Higher peak
- Position: central spot
- A low-energy peak.
- Ratio of face charges
- Develop in time
Possible Xe level

5 mm of Gxe gap
Kyoto Storage Ring

Fig. 1 Layout of the KSR.

beam to LXe prototype