MEG実験 背景ガンマ線の研究

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2010年9月11日

日本物理学会 2010年秋季大会
九州工業大学戸畑キャンパス
Outline

• Introduction
• Pileup
  • Pileup identification
  • Pileup elimination
• Cosmic ray
  • Cosmic ray rejection
• Background components
• Summary
Introduction
Background

What's Necessary for Search?

- Signal
- Back-to-back
- Mono-energetic
- Coincident in time
- A lot of muons
- High intensity
- High duty factor to minimize accidental background
- Good detector
- Precise measurements of energy, timing and angle both for positron and gamma
- Capability to identify pileups

Background

- Prompt background: $e^+\gamma$ (AIF + RD)
- Accidental overlap: $e^+\gamma$

Gamma background (total)

- Single gamma (AIF + RD)
- Pileup
- (Cosmic ray)

This talk

High energy BG events

$R_{acc} \propto (R_\mu)^2 \times (\Delta \theta)^2 \times (\Delta E_\gamma)^2 \times \Delta T \times \Delta E_e$

AIF : positron annihilation in flight
RD : muon radiative decay
Liquid Xenon Calorimeter

Non-segmented detector

→ all PMTs are used to reconstruct each single photon

Expanded view
(Color code = PMT charge)
Energy deposit in LXe (Example 1)

Color represents time (blue -> red)
Energy deposit in LXe (Example 2)
Energy deposit in LXe (Example 2)
LXe pulse

<table>
<thead>
<tr>
<th></th>
<th>NaI</th>
<th>BGO</th>
<th>GSO</th>
<th>LSO</th>
<th>LXe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective atomic number</td>
<td>50</td>
<td>73</td>
<td>58</td>
<td>65</td>
<td>54</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>3.7</td>
<td>7.1</td>
<td>6.7</td>
<td>7.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Relative light output (%)</td>
<td>100</td>
<td>15</td>
<td>20-40</td>
<td>45-70</td>
<td>80</td>
</tr>
<tr>
<td>Decay time (nsec)</td>
<td>230</td>
<td>300</td>
<td>60</td>
<td>40</td>
<td>4.2, 22, 45</td>
</tr>
</tbody>
</table>

Fast decay ➔ Good to reduce pileup

All waveforms are recorded ➔ offline pileup identification
Energy reconstruction

1. Weighted photon sum

\[ N = \sum Q_i / g_i / q e_i \times w_i \]

- Weighted photon sum
- Variation of light yield
- Non-uniform response in the detector
- 5% difference depending on position and depth

2. Correction of

- Non-uniform response in the detector
- 5% difference depending on position and depth
- Variation of light yield

3. Scale to energy. (Single factor)

Required

- Charge of most of PMT
- Position and depth of conversion point
Pileup
How pileup gamma look

Random trigger data

Negative energy is due to overshoot of shaped WF

Most of pile up is low energy

*shaping is done to reduce slow component noise
ID by charge distribution

Example 1

Example 2

Peak search in the largest faces (inner and outer)
Time fitting $\chi^2$

Reconstruction : Fitting $T_i'$ distribution

$T_i' = T_i - d_i / c'$

c' : speed of scintillation light in LXe

Single gamma (MC)

Data

$\gamma$

$\chi^2$/NDF

a.u.
Thought

Easiest way is rejecting all the pileup events

Real signal can be pileup!

→ **Simple rejection make inefficiency**

15% of events of MEG data sample have pileup.

Better way is unfolding pileup gamma, but not trivial.
- MEG calorimeter is non-segmented.
- Light distribution is not constant
  - Low energy → point-like
  - High energy → shower shape is approximately constant.
  - Middle energy → Light distribution much different event-by-event.
- Position and depth of low energy photon is difficult

Subtract pileup energy from total energy
Pileup elimination

Finding pileup gamma positions

Estimating energy without using PMTs around the pileup

Expecting #photons of PMTs in case of no pileup

Replace #photons around the pileup

Doing the usual reconstruction
Finding pileup gamma positions

Estimating energy without using PMTs around the pileup

Expecting #photons of PMTs in case of no pileup

Replace #photons around the pileup

Doing the usual reconstruction

Energy is estimated by fitting main gamma PMTs, without using PMTs around pileup

Fitting function is made from calibration 17MeV gamma data
Finding pileup gamma positions

Estimating energy without using PMTs around the pileup

Expecting #photons of PMTs in case of no pileup

Replace #photons around the pileup

Doing the usual reconstruction
Finding pileup gamma positions

Estimating energy without using PMTs around the pileup

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Doing the usual reconstruction
Pileup elimination

Finding pileup gamma positions

Estimating energy without using PMTs around the pileup

Expecting #photons of PMTs in case of no pileup

Replace #photons around the pileup

Doing the usual reconstruction

Energy of pileup gamma is estimated from information of main gamma. Only a part of PMTs are replaced, and most of original information is used for reconstruction.
Enhanced pileup elimination

Pileup-elimination algorithm can subtract a part of energy (i.e. not all) from pileup.

PMTs in white circles and a trapezoid are replaced.

A correction of subtraction is needed.

correction factor = 2.5 is reasonable from calibration data.
A check by using 55MeV calibration gamma

Before elimination

Black : Pileup all rejected
Blue : Only pileup events

After elimination

Black : Pileup all rejected
Blue : Only pileup events, with enhanced pileup elimination

Resolution becomes almost same

Vertical scale is arbitrary. Background condition during calibration run is much different from physics runs.
Gamma spectrum in physics runs

Before elimination

Pileup rejected

Only pileup, pileup not eliminated

Elimination

[MeV]
Check of the Gamma spectrum in physics runs

After elimination

Blue one is scaled for comparison

Signal region

All pileup rejected.

Only pileup events after elimination

Almost same shape in pileup and non-pileup events. Still investigations are needed for higher tail.
Cosmic ray
Most of CR peak at 160 MeV and higher
tail (Landau)
→ Not background

Low energy part around signal
- Mostly reconstructed around edge.
  → Outside of acceptance
  Automatically rejected.

- CR enter from outer face and stop
in LXe volume can be identified
by unusual light distribution.
Identification needed.

- CR (or secondary particle) enter from
inner face and stop in LXe can be
accidental background
Cosmic ray rejection

Rejection of particles enter from outer face

99% efficiency for signal
56 % rejection in the signal energy range
Background components

Fitting gamma data with background components models
1. **Single gamma (AIF+RD)**

   MC x detector response

   AIF : positron annihilation in flight
   RD : muon radiative decay

   Different pileup due to beam tuning (red and blue)
   Figure is before convoluting detector response

2. **Pileup**

   Random trigger data

   Trigger veto for high energy is taken into account.

   80% of CR can be rejected by random trigger data

3. **Cosmic ray**

   Spectrum of CR (measured)

   Energy [MeV]

   Entries 58236

   **Correlation with positron is not taken into account.**

   **Rate [Hz/MeV]**

<table>
<thead>
<tr>
<th>Energy [MeV]</th>
<th>Rate</th>
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<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

   **Entries 11888**

   Energy [MeV]

   **Histogram**

   **Depth dependence of the variable.**

   Figure 7.40: tau Q for which resolutions are not as good as those for normal depth events.

   The rate of low energy backgrounds from cosmic rays is much lower than that of events cut by the selection is 3.7 px and those events are mostly deep events.

   **Cosmic ray event rejection**

   Most of cosmic ray event can be clearly distinguished from gamma ray events.

   **Entries 58236**

   **5 Hz**

   Trigger veto for high energy is taken into account.
Fit to data

Gamma = AIF + RD + Pileup

(This fitting is done for much wider region than physics analysis)
Background components

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>RD+AIF (Single gamma)</td>
<td>93%</td>
</tr>
<tr>
<td>Cosmic ray</td>
<td>1%</td>
</tr>
<tr>
<td>All the rest</td>
<td>6%</td>
</tr>
</tbody>
</table>

Signal region:

- CR
- AIF+RD
- Total
- All the rest

All the rest: pileup or reconstruction tail
Summary

• Gamma background of MEG
  • Main background source is single gamma from RD or AIF
    • Improvement of resolution must decrease background
        • 13pSM (白雪) : 液体キセノン検出器の性能
  • Cosmic ray
    • Negligible after a simple geometrical rejection
  • Pileup
    • Identification by space, and time methods
    • Analysis to eliminate pileup gamma energy was developed
      • We can use also pileup events for physics analysis *
      • Fraction would become larger when we increase beam rate.

* Large (>13MeV) and negative pileup events are discarded
Back up
Estimation of energy

Excellent resolution is not required, since replaced PMTs are not so many (≤100) typically.

Fitting PMTs except around pileup,

\[ E_i = C(u, v, w, i) \times N_i \times l_i^2 \]

\[ \sigma_i = E_i / \sqrt{n_i} \]

C : Conversion factor
N : Number of photons
l : distance from conversion point to PMT center
n : number of electrons

C is extracted from CW data for 36×96×24×846, stored in a BIG table file.

In principle, everything (except time dependence) must be included. (i.e. depth or position dependence, scatter, error of PMT calibration...)

u v w PMT 300 MB
Expecting and replacing PMT output

Expectation can be done opposite way of energy fitting

\[ N_i = \frac{E}{C(u, v, w, i)} / l_i^2 \]

Currently, PMTs in a fixed distance (30 cm) from the pileup are replaced.
We could do some study to change it event-by-event.
Including time information to eliminate pileup

- Up to now pileup-ID by time is used only to reject events.
- In case of double-pileup, and if one of them is not identified by space, one of pileups is not eliminated but the event is used in analysis. => can make background.
- Probability is very small. \( (P_{\text{pileup}} \times P_{\text{not_IDed}})^2 \)
- Indices of rejected PMTs in time fitting, PMT time is far from gamma time than certain threshold, is written in result folder.
- Modifications
  - These PMTs are not used in energy-fitting.
  - #photon of these PMTs are replaced by expectation from main gamma.
Fraction of eliminated energy

We can know the fraction from CW data.

Enhancement by 2.5 is reasonable
Absolute background rate

Trigger threshold

Data
MC (no pileup)
RD
AIF

Rate (Hz/0.50 MeV)

10^2
10
1
10^{-1}

E_\gamma (MeV)

40 45 50 55 60

MC
3.7 \times 10^7 \mu \text{ decay/sec}
Detector response taken into account
No pileup
Uncertainty ~ 7%

Data
Self trigger data in 2008
Event selection and efficiency

- Event-selection
  - No selection on conversion depth
  - CR is rejected
  - Large (>13 MeV) and negative pileups events are rejected for safety.
  - Pileup event identified by time method, not by charge-distribution method are rejected. (Pileup elimination is not possible)
- Analysis efficiency is calculated from event-count “before” and “after” the cuts and corrected to signal efficiency known from MC

In 2009 run

\[
0.58 = 0.65 \times 0.89
\]

Experiment requirement is 0.6 %
ID by sum waveform shape

Chi-square of template-fitting to sum-waveform

BG rejection $\sim 1$-$2\%$ after applying other methods
Signal inefficiency $< 1\%$

Because other methods, shown previous slides, work enough, this method is not used so far.