Development status of low momentum $e^+$ calorimeter to identify BG gamma ray from radiative $\mu^+$ decay in MEG II experiment

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1. Introduction

- Accidental BG is the most dominant in $\mu^+ \rightarrow e^+\gamma$ search

**Signal**

- $\mu^+ \rightarrow e^+\gamma$

**Accidental BG**

- Low momentum $e^+$
- $\mu^+ \rightarrow e^+\gamma$
- $\mu^+ \rightarrow e^+\nu_e\nu_\mu$

- $\nu_\mu$ + $\nu_e$

- Radiative Decay

- Michel Decay

- RDC (Radiative Decay Counter) in MEG II experiment

**Upstream detector**

- Scintillation fibre

**LXe detector**

**Downstream detector**

- Plastic scintillator + LYSO calorimeter

Measuring energy to separate Radiative Decay from Michel Decay
1. Introduction

- **LYSO (Lutetium-Yttrium Oxyorthosilicate) crystal for scintillator**
  - $2 \times 2 \times 2 \text{cm}^3$
  - Great resolution, large light output
  - Quick decay time to prevent piling up $e^+$ signals
  - Intrinsic radioactivity of Lu used for energy calibration

- **MPPC (Multi-Pixel Photon Counter) for reading out scintillation light**
  - Hamamatsu, S12572-025P
  - 25μm pixel pitch

**Calorimeter behind the plastic scintillator (76 channels)**

- $e^+$ energy 2~5MeV (200~600kHz)
- Desire resolution ~8% @1MeV

**Typical energy ~600keV (2kHz)**

- With reflector

**Sensor (3×3mm²)**
2. Development status

- R&D
  - RDC prototype test
  - MPPC & crystal selection
  - Holder & PCB design
  - LYSO mass test

Remaining tasks
- Optical coupling test
- Afterglow study

- Assembling and operation test
  - Assembling the calorimeter
  - Development of mover
  - Operation test with plastic scintillator

MEG II engineering run / data taking in 2016
3. Optical coupling test

- Performance evaluation of optical coupling between MPPC & LYSO crystal
  → It can make energy resolution better

<table>
<thead>
<tr>
<th>No material</th>
<th>Pad</th>
<th>Film</th>
<th>Grease</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPPC is directly attached</td>
<td>Saint Gobain BC-634A, t=1mm</td>
<td>TOMOE Gaw FW-205, t=20µm</td>
<td>Eljen technology EJ-550</td>
</tr>
</tbody>
</table>

- Experimental setup

  MPPC
  Press with spring pin
  LYSO with reflector

  → NIM amplifier
  → Waveform digitizer DRS (developed in PSI)
3. Optical coupling test

- Evaluation method
  → Energy resolution calculated from the charge distribution

- Charge and energy resolution at 1.17MeV
3. Optical coupling test

- Comparison of pad & grease
  → Over voltage = 3.56V

> The performance changed little with reduced grease
> Amount reduced by half in No.2,4,6
> The performance becomes same as pad at worst

- We will use grease for optical coupling
4. Afterglow study

- LYSO crystal has afterglow (AG)
  - Some excited e\(^-\) trapped in lattice defects
  - Emitted late \(\gamma\) becomes noise
  - Influence on current & energy resolution

- AG is caused by both room light & radiation
  - We want to check all crystals with radiation, but it takes long time

- So we checked all crystals with room light first
  - Then check the correlation with radiation
4. Afterglow study

- **Room light AG**
  - Current of MPPC was measured
  - Over voltage = 4.02V
  - Large individual difference was found
    (~5μA without AG)
  
  All LYSO crystals exposed to room light over 24h

- **Current monitor with $^{90}$Sr (~200kHz)**
  - Temperature was constant (26.0°C )
  - Over voltage = 3.56V
  - Current increased slowly (~30μA in 200days)

Current was measured in every 10sec
5. Assembling the calorimeter

- Holder design

- LYSO crystal with reflector

- 22cm

- Steel blocks for dummy channels

- 200μm Al plate

- 0.8mm Delrin®

- Light shielding

- e⁺ incoming direction

- Tighten with screw
5. Assembling the calorimeter

- PCB design
  → MPPC are pressed with spring

- No dead channel was found in PCB
  → LYSO intrinsic radioactivity was observed in all channels
6. Summary

- Optical coupling between MPPC and LYSO crystal was optimized
  - We will use grease for optical coupling

- Afterglow of LYSO crystal was studied
  - All LYSO crystals were measured with room light
  - Increased current was observed with radiation
  - We should check correlation with AG from radiation and estimate effect on resolution

- Construction of the calorimeter has just started
  - No dead channel were found in PCB
  - We should combine plastic scintillator and test
THE END
BACK UP
Michel Decay & Radiative Muon Decay

* e⁺ energy deposit from simulation

Radiative Muon Decay

Michel Decay

RMD (Eγ > 48 MeV)
MPPC selection

- **Advantage of using 25μm pixel pitch compare to 50μm**
  - Crosstalk becomes smaller due to lower gain
  - Saturation can be minimized
  - Current also becomes smaller

- **50μm pixel pitch is superior in S/N ration**
  - Signal can be seen more clearly
  - But we can obtain desire resolution with 25μm pixel pitch
Reflector design

* Enhanced Specular Reflector Film (ESR)

→ 65μm thickness
Charge vs Resolution

![Graph showing the relationship between Charge (C) and Resolution (%). The graph compares Pad (red stars) and Grease (green stars).]
Temperature & current

![Graph showing charge vs. temperature and current for Pad and Grease samples.](image)
Afterglow mechanism

Reference

- LYSO crystal structure
  → O₅ has the lowest formation energy
  → Oxygen vacancies can be created during crystal growth due to the low oxygen content in the furnace atmosphere

- Emission spectrum & Thermoluminescence
  → Afterglow depends on its growth atmosphere
  → Strong peak around 340K
Room light afterglow recheck

- Red & Blue plot shows another measurement results

→ Room light exposed over 48 hours after light shielding
Afterglow study
Afterglow study

- We also checked other 2 crystals only for ~60h
  - Over voltage = 3.56V

- Effect on energy resolution with rising of 50μA
  - Statistical contribution from number of AG photoelectrons was calculated
  - Single waveform contains $N_{\text{all}} = N_{\text{sig}} + N_{\text{AG}}$

  Resolution = \[\frac{\sigma_{\text{all}}}{N_{\text{sig}}}\]
  \[= \frac{\sqrt{N_{\text{sig}} + N_{\text{AG}}}}{N_{\text{sig}}}\]
  \[= \frac{1}{\sqrt{N_{\text{sig}}}} + \text{terms with } N_{\text{AG}}\]

  Assuming Poisson distribution
  \[\sigma_{\text{all}}^2 = \sigma_{\text{sig}}^2 + \sigma_{\text{AG}}^2\]
  \[\sigma_{\text{sig}} = \sqrt{N_{\text{sig}}}\]
  \[\sigma_{\text{AG}} = \sqrt{N_{\text{AG}}}\]

  Measured $N_{\text{sig}}$ & $N_{\text{AG}}$
  \[N_{\text{AG}} \approx 401\]
  \[N_{\text{sig}} \approx 3090\]

  This additional terms ~0.2%
Energy resolution calculation

- How much resolution gets worse if p.e. from AG are increased
- 2 assumptions

1. Single waveform contains $N_{\text{all}}$ photoelectrons

\[ N_{\text{all}} = N_{\text{sig}} + N_{\text{AG}} \]

2. $N_{\text{AG}}$ shifts mean value in charge distribution

Resolution = \[ \frac{\sigma_{\text{all}}}{N_{\text{all}} - N_{\text{AG}}} \]

= \[ \frac{\sigma_{\text{all}}}{N_{\text{sig}}} \]
Energy resolution calculation

Resolution = \frac{\sigma_{all}}{N_{\text{sig}}} 
= \frac{\sqrt{N_{\text{sig}} + N_{\text{AG}}}}{N_{\text{sig}}} 
= \frac{1}{\sqrt{N_{\text{sig}}}} \sqrt{1 + \frac{N_{\text{AG}}}{N_{\text{sig}}}} 
= \frac{1}{\sqrt{N_{\text{sig}}}} + \text{terms with } N_{\text{AG}}

N_{\text{all}} = N_{\text{sig}} + N_{\text{AG}} 
\sigma_{\text{all}}^2 = \sigma_{\text{sig}}^2 + \sigma_{\text{AG}}^2

If it follows a Poisson distribution…

\sigma_{\text{sig}} = \sqrt{N_{\text{sig}}} \quad \sigma_{\text{AG}} = \sqrt{N_{\text{AG}}}

\Rightarrow \sigma_{\text{all}} = \sqrt{N_{\text{sig}} + N_{\text{AG}}}

We can estimate additional terms from $N_{\text{sig}}$ & $N_{\text{AG}}$
Energy resolution calculation

- Consider waveform of 1.17MeV Co60 peak

\[
N_{AG} = \frac{\text{Current}[c/s] \times \text{Wavelength}[s]}{\text{Gain of MPPC} \times e[c]}
\]

\[
N_{\text{sig}} = N_{\text{all}} - N_{AG} = \frac{\text{Charge at 1MeV}}{\text{Charge at 1p.e.}} - N_{AG}
\]

- If current is increased 50\(\mu\)A...

\[
N_{AG} \approx 401
\]

\[
N_{\text{sig}} \approx 3491 - 401 = 3090
\]

Resolution gets worse \(\sim 0.2\%\)
Pictures of PCB
Springstand