MEG II実験のための背景ガンマ線同定用低運動量陽電子タイミングカウンターの実機製作と性能評価

Development status of low momentum positron timing counter to identify BG gamma ray from radiative muon decay in MEG II experiment

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CONTENTS

- MEG II Experiment
- Radiative Decay Counter (RDC)
- Status & Schedule
- Scintillator Test
- MPPC Grouping
- Counter Production & Test
- Summary & Prospect
diamond \( \mu \to e\gamma \) decay search

- In standard model with neutrino oscillation, the branching ratio is too small to detect the decay: \( \sim O(10^{-54}) \)
- On the other hand, some beyond standard models predict large branching ratio: \( \sim O(10^{-14} - 10^{-13}) \) whose level our experiment can reach!!
- Discovery of \( \mu \to e\gamma \) = Discovery of new physics

diamond **Signal Event**: 2-body decay from a muon at rest

- Both \( e^+ \) and \( \gamma \) have a **monochromatic energy** (52.8 MeV)
- They are emitted **time-coincidently**, and
- back to back

high precision measurement of energy, timing and opening angle of \( e^+ \) and \( \gamma \)
Upgrade of MEG Experiment

- Doubled beam rate: $7 \times 10^7$ muons/s
- PMTs in LXe Detector are partially replaced with MPPCs
- A low mass stereo drift chamber
- A multi-tile scintillation timing counter
- New BG tagging detector is introduced

MEG II EXPERIMENT

T.Iwamoto(27aSN-8), S.Ogawa(27aSN-10), K.eki(27aSN-9)

Status: Y.Uchiyama (25aSG-2)

MEG I
Upper Limit: $5.7 \times 10^{-13}$ (90% C.L.)

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MEG II
Sensitivity Goal: $4 \times 10^{-14}$

S.Nakaura (28aSG-7), R.Iwai (28aSG-8)

M.Nishimura(26aSN-1), M.Nakao(26aSN-2), K.Yoshida(26aSN-3)
Main Background Event: accidental background

- Radiative Decay Counter (RDC) tags Radiative Muon Decay actively

16 ~ 28% higher sensitivity can be achieved by introducing RDC

<table>
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<th>Scenario</th>
<th>Sensitivity</th>
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<tr>
<td>without RDC downstream</td>
<td>$5.0 \times 10^{-14}$</td>
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<td>with RDC downstream</td>
<td>$4.3 \times 10^{-14}$</td>
</tr>
<tr>
<td>with full RDC</td>
<td>$3.9 \sim 4.1 \times 10^{-14}$</td>
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</table>

16~28% depending on detection efficiency (50%~80%)

1. Radiative Muon Decay
2. Annihilation in flight
Active tagging of Radiative Muon Decay

- Radiative Muon Decay with a high energy (> 48 MeV) gamma ray simultaneously emits a low momentum positron (typically: ~5 MeV).

- It has small turning radius
  - Small counters are set on the beam axis

- measure time coincidence between γ and low momentum e⁺

- measure energy of e⁺ to distinguish Radiative Decay from Michel decay

\[
\begin{align*}
\text{e}^+ &\text{ momentum} \\
0 &\rightarrow 10 \\
0.04 &\rightarrow 0.16 \\
0.10 &\rightarrow 0.16
\end{align*}
\]

\[\begin{align*}
\text{RDC detects} \quad &\text{e}^+ \quad \text{from RMD} \\
\text{RDC} \quad &\gamma \quad \text{from RMD} \\
\text{Muon beam} \quad &\text{Drift chamber} \\
\text{Timing counter} \quad &\text{e}^+ \quad \text{from RMD} \\
\text{Accidental e}^+ \quad &\text{from Michel}
\end{align*}\]
**Upstream RDC**

- Made of 704 plastic scintillation fibers
  - thickness = 250 μm
  - small effect on μ⁺ beam transportation
- Separate μ⁺ from e⁺ using difference of energy deposit
- Measure **time coincidence** between γ and e⁺ (from radiative decay)

**The effect on the μ⁺ beam properties?**

- In simulation,
  - stopping efficiency will be decreased by 3%:
    - 71.9% (w/o RDC) → 69.8% (w/ RDC)
  - A small influence on the beam spread (6~7%).
    - σ X: 1.11 cm (w/o RDC) → 1.19 cm (w/ RDC)
    - σ Y: 1.07 cm (w/o RDC) → 1.13 cm (w/ RDC)
- We plan to measure it with beam using a mock-up detector in this Autumn.
◇ Downstream RDC

- Already approved by the collaboration
- 12 Plastic scintillation bars
  - length: 7 ~ 19 cm, width: 1 ~ 2 cm, thickness: 5 mm
  - measure time coincidence between $\gamma$ and $e^+$
- 76 LYSO crystals
  - $2 \times 2 \times 2$ cm$^3$
  - measure energy deposit and distinguish Radiative Decay and Michel Decay
Plastic scintillator

- BC-418 (Saint-Gobain)
  - large light yield
  - fast response (decay constant: 1.4 nsec)
- Two types of width: 1 cm & 2 cm
  - 1 cm: for reducing pileup events
- Series connected MPPCs
  - sharpen waveforms
- PCBs: compact readout circuits
  - MMCX cables are used.
  - 3 narrow bars are attached on a long PCB
- Required time resolution ~ 100 psec
## STATUS & SCHEDULE

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Plastic scintillator

**setup**

- 12 scintillation bars were tested.
- MPPCs were attached on both sides of a scintillation bar.
- 2 or 3 MPPCs were connected in series.
- optical grease was used for coupling.
- radioactive source: $^{90}$Sr.
- trigger: hit in reference counter.

- calculate $\left[ T(ch1)+T(ch2) \right]/2 - T(\text{reference})$
- constant fraction time
- Fit the distribution with Gaussian function and the $\sigma$ is defined as time resolution

**Result:** 120-145 psec

- This value includes resolution of the reference counter.
  (the resolution of reference counter: $\sim$100 psec)
- The resolution of the bars is good enough.
MPPCs for plastic scintillator

- **Grouping**
  - there are 12 scintillation counters
    - MPPCs are divided into 24 groups
  - measure I-V curve for all of MPPCs
  - MPPCs which show close I-V shapes are put in the same group.

### Why?

3 MPPCs in series
- Operation voltage (~2.6V)
- Breakdown voltage
- Common current
- The same I-V shape $\rightarrow$ the same overvoltage
◊ PCB design

- Consists of 4 layers:
  - shield layers on both sides for noise suppression

- Capacitors for noise reduction
  - connecting ground of MPPCs with chassis ground
    (this is effective on reducing noise by our experience)
  - avoid ground loop.
◇ Assembling

- Conductive epoxy (CW2400)
  - attach MPPCs to a PCB without heating
  - strong mechanical bonds
  - good electrical conductivity

- Alignment jig
  - a π-shaped acrylic part for y-direction alignment
  - oil coated (small friction)
    → avoid glue adhering
  - an acrylic part for x & z direction alignment

POM parts
Assembling

- Optical cement
  - used for coupling between PCBs and scintillation bars
    - aligned with the jig

- Aluminized mylar
  - used as a reflector

3 counters have been assembled
Counter Test

- Time resolution of assembled counters

\[ \frac{T_{\text{ch1}} + T_{\text{ch2}}}{2} =: T_{\text{mean}} \]
\[ \frac{T_{\text{ch3}} + T_{\text{ch4}}}{2} =: T_{\text{ref}} \]

\( T_{\text{mean}} - T_{\text{ref}} \) distribution

<table>
<thead>
<tr>
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<th>time resolution</th>
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<td>15 cm</td>
<td>71 psec</td>
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<tr>
<td>19 cm</td>
<td>104 psec</td>
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</table>

→ good enough for RDC

\( ^{90}\text{Sr} \) was put on the center of counters

\( ^{90}\text{Sr} \) frame for plastic scintillators

The smallest counter was used as a reference counter

\( \sigma \sim 65 \text{ psec} \)
Summary

- 16 ~ 28% sensitivity improvement will be achieved by introducing RDC.
- Downstream RDC has already been approved.
- Plastic scintillator bars have arrived and showed good time resolution.
- Counter production has started.
- Assembled counters showed good performance.

Prospect

- Finish counter production and their test
- Combine plastic scintillator part with LYSO part, and test them as overall downstream RDC.
  → Downstream RDC will be prepared by the end of this year.
- Study on Upstream RDC with beam will be started this autumn.
BACKUP
Plastic scintillator

<table>
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<tr>
<th>Scintillator</th>
<th>Light Output % Anthracene¹</th>
<th>Wavelength of Maximum Emission, nm</th>
<th>Decay Constant, Main Component, ns</th>
<th>Bulk Light Attenuation Length, cm</th>
<th>Refractive Index</th>
<th>H:C Ratio</th>
<th>Loading Element % by weight</th>
<th>Density</th>
<th>Softening Point °C</th>
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¹ Anthracene light output - 40-50% of Na(I)  
* 0.1 to 5 weight % also available  
** Ratio of Cerenkov light to scintillator light = 10:1

MPPCs in series

COUNTER PRODUCTION & TEST
◇ MPPCs for plastic scintillator

- MPPC (Multi-Pixel Photon Counter)
  - S13360-3050PE
  - pixel size: 50×50 μm²
  - crosstalk suppression
  - 2 or 3 series connection
  - 60 MPPCs are used