MEG II 実験の背景事象の抑制に向けた超低物質量RPCの開発と性能評価

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Contents

● Introduction
  ✓ MEG II experiment
  ✓ Background identification detectors for MEG II background
  ✓ RPC with DLC sputtering technique
  ✓ Required studies for MEG II

● R&D for RPC

● Summary and prospects
MEG II signal and background

- MEG II will search for $\mu \rightarrow e \gamma$ rare decay
  - Identified by energy, timing and direction of e and $\gamma$

- Dominant source of background is accidental coincidence of BG-e and BG- $\gamma$ mimicking the signal
  - One of the dominant source of BG- $\gamma$ is radiative muon decay

![Radiative Muon Decay Diagram]

- Opposite direction
- 52.8 MeV
- Same timing

both 52.8MeV
Background identification detector

- New detectors to identify BG- $\gamma$ from radiative muon decay will be installed for further sensitivity improvement
  - Detect low energy positron (1-5MeV) accompanying BG $\gamma$ (~53MeV)

- Planned to be installed to 2 sites
  - Upstream and downstream of the target
  - Upstream one is under development → Today’s talk

**Figure 3.1:** Schematic view of MEG II detectors

**Figure 3.2:**
- COBRA magnet
- $\gamma$ detector
- $e^+$ (Michel)
- $e^+$ (RMD)
- $\nu_e$ (RMD)

RDC

<table>
<thead>
<tr>
<th>1-5 MeV, detect this</th>
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<tbody>
<tr>
<td>52.8 MeV</td>
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**Chapter 3**

3.1 Principle of background identification

- The concept of the RDC is illustrated in Figure 3.1. As previously mentioned, a positron emitted from the target follows a trajectory along the gradient magnetic field, which is produced by the COBRA magnet. When a high energy photon is emitted from RMD, a low momentum positron on the beam axis. The detectors can be installed at both upstream and downstream of the muon stopping target. Figure 3.2 shows the expected hit timing distribution for positrons. According to the simulation result, 41% of total background photons can be rejected.

3.2(a) RMD

- $\gamma$ decay
- $e^+$ decay

3.2(b) AIF: Annihilation In Flight

- $e^+$ decay

3.1.2 AIF: Annihilation In Flight

- $e^+$ decay

3.2 Radiative Muon Decay

- $e^+$ decay
Upstream BG identification detector

- Difficulty of upstream detector is the $\mu$ beam (100 MHz) passing through the detector

Requirements for upstream detector

1. Detection of 1-5 MeV positron
2. Timing resolution: $\sim$1 ns
3. Rate capability and radiation hardness
   (100 MHz of $\sim$21 MeV/c muon, 60 week run)
4. Material budget: $< 0.1\%$ of $X_0$
5. Detector size of 20 cm diameter

- Candidate: RPC using electrodes based on Diamond Like Carbon (DLC)
RPC based on DLC

- **RPC**: gaseous detector with resistive electrodes parallelly placed
  - R134a based gas with iso-butane & SF6 quencher
  - Gas gap is typically several hundred μm

- We use electrodes fabricated by sputtering DLC on 50 μm Kapton films
  - DLC: high-resistive material made of carbon (mixed structure of sp² bond and sp³ bond)
  - Advantage of DLC: low material & adjustable resistivity
  - Technology developed by Kobe University
Required studies

- Design parameters to be optimized
  - Gap thickness
    - determines timing resolution and detection efficiency
  - Resistivity of electrode surface
    - determines rate capability of the detector
  - Readout structure
    - affects pileup probability, timing resolution
Contents

• Introduction

• R&D for RPC based on DLC electrodes
  ✓ Structure
  ✓ Performance measurement and result
  ✓ Readout test

• Summary and prospects
Prototype design

- Performance study is conducted using 4cm×5cm size plate
  - DLC films are put face to face with a gap of 200 μm
  - Single layer

![Diagram](image)

- DLC sputtered on the front side
- 200 μm pillars are attached on the DLC film

4cm × 5cm copper is attached for readout on the reverse side

4×5cm copper

LEMO

Kapton (50 μm)

readout
Setup for performance measurement

gas mixture: R134a/iso-C$_4$H$_{10}$/SF$_6$ = 94.8/4.7/0.5

Detection efficiency and timing resolution are measured in this setup
Performance: efficiency

- Efficiency: 23%
- ✓ 9mV pulse height threshold is set considering the noise level

![Graph showing RPC pulse height spectra with a peak at 200 μm gap, 1650V.](image)

- Entries: 41590
- Mean: 0.002993
- Std Dev: 0.002135
Performance: timing resolution

- Timing resolution: 360 ps

RPC timing is measured at 50% constant fraction

- Distribution of timing difference b/w reference counter & RPC
- 360ps fitting parameter
Required improvements

● The readout should be made of Aluminium because copper has large material itself.
  (Commercial aluminized Kapton has thin Al layer with non-negligible resistivity, which may cause problem)

● Multilayer RPC is favored to achieve higher efficiency, but the number of layers is 4 at maximum (limited by material budget)
  ✓ 40% single layer efficiency is desired (Total 90% efficiency in reach)

● To achieve high rate capability, the readout must be segmented
  ✓ Strip shape readout is considered
Readout test: signal waveform

- Strip shaped Al readout is tested

1. 4x5cm copper

2. 1x10cm Aluminium (100nm thickness)

- No problem in the signal waveform
Readout test: timing resolution

● Timing resolution: 290 ps
   ✓ Asymmetry of the distribution is not understood
Contents

- Introduction
- R&D for RPC based on DLC electrodes
- Summary and prospects
Summary

- 23% efficiency is achieved with single layer 200 $\mu$m gap RPC
  $\Rightarrow$ It has not reached the goal of 40% for single layer setup

- Timing resolution is 300-400ps for 200 $\mu$m
  - Better than the requirement
    (dependence on readout scheme is also found)
  - It may be worsened when wider gap is used

- It has been demonstrated that Aluminium readout works
  $\Rightarrow$ 0.1% $X_0$ requirement can be achieved (not completed)
Prospects

- Performance with larger gas gap (400-500um) to be measured

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<tr>
<th>Pros</th>
<th>Cons</th>
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<tr>
<td>• better efficiency</td>
<td>• higher operating voltage</td>
</tr>
<tr>
<td></td>
<td>• worse timing resolution</td>
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- Further studies on readout configuration is required
  - To pickup the narrow signal shape and suppress reflection of signal
    → important to suppress pileup b/w positron and beam $\mu$
  - To understand the dependence of timing measurement on the readout

- Rate capability measurement
BACK UP
The circuit diagram of the amplifier used to read signal from the RPC

- Developed to read signal from SiPMs with high amplification gain and fast response.
Pulse height and timing relation

2D hist time vs height

- Entries: 9938
- Mean x: 0.02587
- Mean y: -0.6701
- Std Dev x: 0.01572
- Std Dev y: 0.4317
Signal shape

2×4cm copper
Timing resolution

- For 4cm × 5cm readout setup
  - Distribution of timing difference b/w reference counter & RPC
  - 360ps fitting parameter

- 1cm × 10cm showed different timing distribution (This might be unrelated to readout)