DEVELOPMENT OF NOVEL PARTICLE DETECTOR WITH MULTI PIXEL PHOTON COUNTER READOUT

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To my beloved mother, father, brothers and sisters

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ABSTRACT

The purpose of this study is to develop a new muon beam monitor for MUon Science Innovative Channel (MUSIC) project at Osaka University. It was a prototype with the dimension of $20x20x1cm^3$ plastic scintillating counter with wavelength shifting fibers (WLS-Fi) readout to alternate the particle beam to the multi pixel photon counter (MPPC). We are using Strontium-90 as a test source along this research. The data was taken in 10000 events by varying parameters such as number of MPPCs used and the source positions. Raw data will be processed and plotted in a histogram. 12 MPPCs were used to determine light yield by MPPC. A maximum of 10 photons was detected by MPPC nearest to source. It is half of the estimated number of photon which is calculated using formula. Then, we add two photomultiplier tube (PMT) to trigger at opposite direction, we estimated the best position resolution is about 3mm for black sheet condition. As a conclusion, black sheet condition gives best resolution compare to other.

ABSTRAK

Kajian ini dijalankan bagi membina sebuah pengesan bentuk sinaran muon untuk projek MUSIC di Osaka University. Sebuah protaip berukuran 20x20x1cm3 telah dibina menggunakan kaunter scintilator plastik dilengkapi dengan fiber WLS dan disambungkan ke MPPC untuk mengesan bilangan cahaya photon yang dipancarkan oleh unsur Beta. Bilangan MPPC ditambah secara genap bagi melihat kesan bilangan photon apabila MPPC berada jauh daripada unsur Beta. Sebanyak 10000 bacaan telah diambil sambil mengubah kuantiti MPPC dan posisi unsur. Bacaan akan diproses dan diplot ke dalam histogram. 12 buah MPPC telah digunakan bagi mengira bilangan cahaya pada MPPC. Sebanyak 10 photon telah dikesan pada MPPC tetapi ia adalah separuh daripada nilai kiraan menggunakan teori. Kemudian, 2 PMT telas diletakkan pada arah berlawanan dan hasilnya resolusi pengesan bertambah baik iaitu 3mm. Kesimpulannya, kajian susulan harus dijalankan bagi memperbaiki resolusi pengesan bagi menghasilkan pengesan yang tepat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

MUSIC	MUon Science Innovative Channel
MPPC	Multi Pixel Photon Counter
WLS	Wavelength Shifting
PMT	Photomultiplier Tube
PDE	Photon Detection Efficiency
PRISM	Phase Rotated Intense Slow Muon Source
FFAG	Fixed Field Alternating Gradient Ring
LIDAR	Light Detection and Ranging
OTDR	Optical Time Domain Reflectometry
DAQ	Data Acquisition System
PC	Personal Computer
ADC	Analog to Digital Converter

LIST OF SYMBOLS

Q	Magnitude of Charge
C	Capacitance
V	Operating Voltage
V_{bd}	Breakdown voltage
M_s	Center of Mass
m	Integer
N_m	Number of Photon at m
N_L	Number of Photon at left MPPC
N_R	Number of Photon at right MPPC
x	Instantaneous length
L	Fiber length
$\frac{dE}{dx}$	Rate of energy loss of particle with respect to distance
γ	Constant
β	Constant
ν	Muons velocity
c	Speed of light
Z	Atomic number
A	Atomic mass
I	Mean excitation energy
δ	Correction constant
M	Rest mass
T	Solid angle
n_1	Refractive Index 1

n_2	Refractive Index 2
C	Particle passage
N_{calc}	Number of calculated Photon
N_{scint}	Number of Photon first detected by scintillator
P_{fiber}	Probability of attenuation in fiber
P_{att}	Probability of attenuation in scintillator

CHAPTER 1

INTRODUCTION

1.1 Introduction

The discovery of electron 100 years ago had begun the development of elementary particle physics. However, the subject really blossomed after 1950 and thus stimulated the development of high energy accelerators. Elementary is always refers to pointlike or structureless particles. Muon is one of the elemental particles which is in lepton family and like a brother to electron. There are positively-charged and negatively-charged muons. The mass of the muon is about 200 times that of an electron. A positive muon behaves like a light proton. A negative muon behaves like a heavy electron. Muon is unstable; its mean lifetime is about 2.2 microseconds.

To observe this kind of particle, we need to have a high energy particle detector. The classical way of single photon detection is to use a Photomultiplier Tube (PMT). Particularly with a cooled photocathode, such a device can have a very low dark count rate. The quantum efficiency can reach several tens of percent in the visible spectral region, whereas devices for infrared light achieve quantum efficiencies of at most a few percent.

However, PMT has many disadvantages. PMT needs high voltage supply and cannot be used under a strong magnetic field range. PMTs are also very costly and have typically lower quantum efficiency. We are replacing PMT with a new silicon photomultiplier (Si-PM) called Multi Pixel Photon Counter (MPPC).

MPPC have many features which may challenge the capability and sensitivity of PMT. Even though the size and its active area of MPPCs are so small compared to PMTs, it is able to detect photon signals separately. It also can be used under a strong magnetic field range. In this research, a beam monitor with MPPC readout has been developed. This detector aims to measure muon hit position to know beam shape of muons.

1.2 Objectives of the Study

The objectives of this study are:

- To construct a prototype of muon beamline detector.
- To measure the hit position of particle and number of light yield for each MPPCs.

- To calculate the position resolution for different condition

1.3 Scope of the Present Study

This study covers the construction of a muon beamline detector prototype with the dimension of 20x20x1 cm^3. The prototype consists of a box wrapped with black sheet, a plastic scintillator stripped with wavelength shifting fibers and the MPPCs as photon sensors. Position resolutions are examined with beta source (Sr90) at different surface conditions of the plastic scintillator. The details of the measurements are described with the analysis to calculate the position resolutions.

1.4 Significance

Single photon counters are used in various areas of science and technology. Some fields of quantum optics and in particular quantum information technology require single photon detection, often with high quantum efficiency and with a precise timing for coincidence detection. Methods such as light detection and ranging (LIDAR) and optical time domain reflectometry (OTDR) have to work with very low light levels and can therefore profit from photon counting detectors.

MPPC are some kinds of new photodetectors that are so sensitive and they allow the detection of single photon. It is possible to register single photon absorption events, rather than measuring an optical intensity or power. It is also possible to register coincidences between two or more detectors. This is very important and functional for many experiments in quantum optics.

The combination of MPPC with Wavelength Shifting fiber (WLS-fi) may enhance the capability of both components to detect particle. This muon beam monitor is not only capable to detect muons but also heavy particle such as Q-ball and other particles. This detector will be used in the MUon Science Innovative Channel (MUSIC) project at the Osaka University, which will be discussed later in Chapter 2.