PROCEEDINGS OF SCIENCE

# R&D on a gating PMT of Proton Extinction Monitor

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We have proposed an experiment called "COMET (COherent Muon to Electron Transition)" to search for a muon to electron conversion process at J-PARC. In order to avoid the backgrounds related to primary protons, we make use of a pulsed proton beam. The repetition of proton pulses is about 1 MHz, and each proton pulse contains $10^8$ of 8 GeV protons. In order to achieve $10^{-16}$ of branching ratio for muon to electron conversion, a number of protons coming between pulses must be less than $10^{-9}$ to that coming in a main pulse. This ratio is called "proton extinction". We are developing a device to monitor the proton extinction. The proton extinction monitor under my study consists of gas Cherenkov detector with gating photomultiplier tubes (PMT). In order to make it sensitive to 8 GeV protons, Cherenkov radiator gas will be pressured up to 20 atm. Cherenkov lights emitted by primary protons are detected by the gating PMT. The high voltage of the gating PMT is switched at a high frequency such as a MHz to avoid saturation of the PMT from main proton pulses. An electric circuit to meet this requirement is designed and tested. A prototype of the gating PMT was fabricated, and the on/off ratio of $10^{-6}$ has been achived.

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## 1. Introduction

A muon to electron conversion process is one of lepton flavor violation processes, and is sensitive to physics beyond Standard Model. In order to perform the experimental search for this process, COMET (COherent Muon to Electron Transition) experiment was proposed to J-PARC, and currently under the extensive design study [1] .

In the COMET experiment, backgrounds are categorized to four groups: physics background, beam-related prompt backgrounds, beam-related delayed backgrounds and cosmic related backgrounds. The beam-related prompt backgrounds are estimated to be larger than the others. The beam-related prompt backgrounds consist of radiative pion capture, muon decay-in-flight, and beam electron scattering, and the timing of all of these backgrounds are prompt after the hit of primary protons on a production target. Therefore, in order to avoid these prompt backgrounds, a pulsed primary-proton beam will be utilized. Signals of muon to electron conversion will be searched in a timing region of 700 nsec after the proton beam pulse. The repetition of primary proton pulses from the J-PARC Main Ring is about 1 MHz, and each pulse contains $10^8$ of 8 GeV protons. In order to achieve $10^{-16}$ of branching ratio for muon to electron conversion, a number of protons entering to the production target in the delayed timing region must be less than $10^{-9}$ of the number of protons in the main pulses. This ratio is called Proton Extinction Ratio, and it is critically important to control the proton extinction ratio. A proton extinction monitor is a device to measure the proton extinction ratio, and is a key device of the COMET experiment.

Figure 1 shows a schematic figure of the proton extinction monitor. The proton extinction monitor currently under development is a gas Čerenkov detector with gating photomultiplier tubes (PMT) readout. In order to make it sensitive to 8 GeV protons, Čerenkov-radiator gas will be pressured up to 20 atm. According to our study, ethane is found to be the best candidate since the delayed scintillation light yield is very small [2]. Čerenkov lights emitted by primary protons are collected by a mirror and focused on the gating PMT. The high voltage of the gating PMTs is switched on and off at a high frequency (such as a MHz) so that the flash of light coming from the main proton pulse should not produce signal currents in the PMTs. The ratio of PMT gains between off state and on state is called a cutoff ratio, and our goal is the cutoff ratio being less than $10^{-6}$.

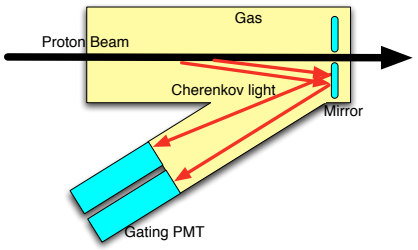


**Figure 1:** A Proton Extinction Monitor: a gas Čerenkov counter read by gating PMTs.

## 2. Development of Gating PMT

In our gating PMT scheme, the off state of the PMT is realized by switching only a part of grids but not all of them. We already found that the switching of both focus grid and the 3rd dynode by 400 V and 300 V, respectively, provides the cutoff ratio being a level of $10^{-6}$ [3] .



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Following the above study performed in 2007, we developed a gating PMT circuit. Figure 2 shows a block diagram of the gating circuit. This circuit was designed for the usage with a linear-focus type PMT model 9954B (Electron Tubes Inc.), where the number of dynodes are 12 with one focus grid. The high voltage in the normal operation is 1700 V.

The result of measurement of cutoff ratio is shown in Figure 3. In the measurement, a solid laser pulse was used to produce a light pulse. ND filters were used to adjust the strength of light pulse. The PMT gain was obtained by measuring the anode signal by a charge ADC. The cutoff ratio we obtained is $10^{-6}$, and the switching time is about 200 nsec. These results are good enough for the operation of the proton extinction monitor. However, during the measurement, we observed one potential impediment. There is quite a number of afterpulses in off state right after switched from the on state. The number of afterpulse is too large to use this device for the proton extinction monitor. The cause of the afterpulse is still under study, but probably due to the ion feed back. The optimization of focus grid potential might cure the problem[4] at a certain level. The potential of the 1st dynode may have to be switched with the focus grid.

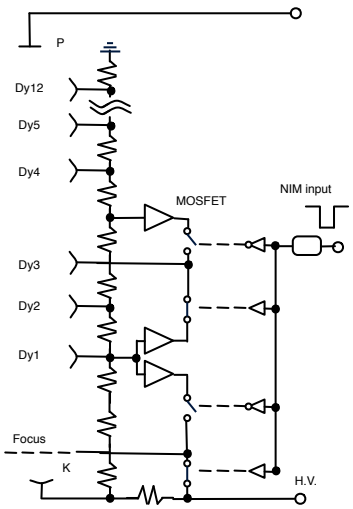


**Figure 2:** Block diagram of a gating circuit. Both a focus grid and the 3rd dynode are switched by MOSFET.

## 3. Summary

COMET is the experiment to search for muon to electron conversion. The control of the proton extinction ratio is a key of the experiment. A proton extinction monitor is a device that measure the proton extinction and the gas-Čerenkov based monitor system is currently under the development. The prototype of gating PMT was fabricated and tested. The cutoff ratio we achieved is $10^{-6}$ for 10 kHz of repetition. Further study in order to reduce the afterpulse is on-going.

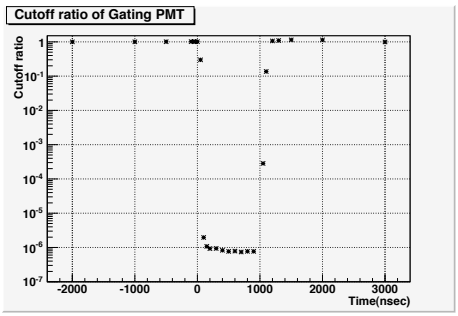


**Figure 3:** The measured cutoff ratio. The PMT is off state from time zero to 1µsec. The vertical axis is the cutoff ratio.

## References

[1] Conceptual
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[2] T. Yano, OULNS annual report 2007, 83.

[3] N. Ito, OULNS annual report 2007, 85.

[4] Hagen, Guy M. *et al*, Rev. Sci. Instrum, 76(2005)pp.083117



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