PROCEEDINGS OF SCIENCE

After-Proton background estimation for DeeMe experiment

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Muon to electron conversion is one of the charged lepton flavor violation (CLFV) processes, which is forbidden in the Standard Model of the particle physics. There are theories beyond the Standard Model of particle physics that predict the existence of muon to electron conversion at the branching ratio level of $\sim 10^{-14}$. DeeMe is an experiment searching for muon to electron conversion with a single event sensitivity of 2×10^{-14} (with a silicon carbide production target) being constructed at J-PARC. DeeMe utilizes 3-GeV 25Hz pulsed proton beam from Rapid Cycling Synchrotron. The beam hits a target and produces muonic atoms in the target. The signal of DeeMe is the 105-MeV electrons directly emerging out of the target with delayed timing. It is very important to understand the mechanism of proton production with delayed timing, if any, and to evaluate the amount of such protons producing electrons that mimic the signal electrons. The expected number of background events coming from the delayed protons was estimated to be less than 0.03 during the design of DeeMe, and the number was limited by the particle identification performance of the delayed-proton monitor. In this paper, the updated design of the monitor will be described in detail.

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1. Introduction

Muon to electron (μ-e) conversion is one of the charged lepton flavor violation (CLFV) processes. CLFV is forbidden in the Standard Model of particle physics. However, some theories beyond the Standard Model predict μ-e conversion signature at the branching ratio level of 10^{-14}.

DeeMe is an experiment searching for μ-e conversion with a single event sensitivity at level 2×10^{-14} (with a silicon carbide production target). DeeMe will be constructed at J-PARC MLF[1]. Figure 1 shows the experimental apparatus of DeeMe. DeeMe utilizes 3-GeV 25Hz pulsed proton beam from Rapid Cycling Synchrotron (RCS). In DeeMe experiment, μ-e conversion occurs in the decay of muonic atom (an atom that traps a negative muon in its atomic orbit). The electron converted from the trapped muon has the energy of 105 MeV with a delay of a few μs from the pulsed-proton timing. The electron signals are distinguished by their momenta and time information.

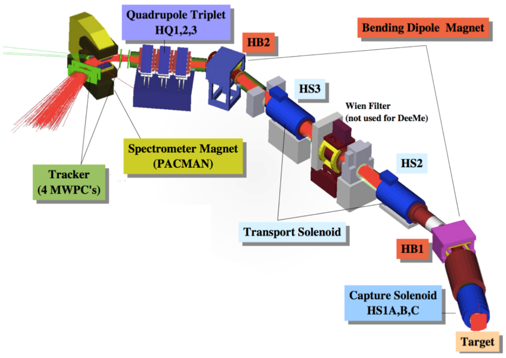

Figure 1: A schematic view of the experimental apparatus of DeeMe experiment including a secondary beamline used for DeeMe.

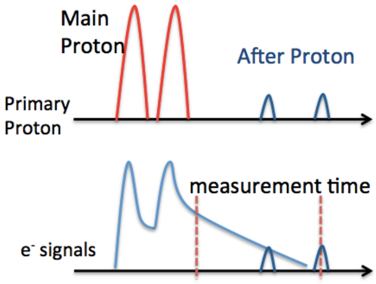

Figure 2: An illustration of the time distribution of main proton pulse, after-protons and electrons to explain the production mechanism of the after-proton backgrounds.

2. After-Protons

After-Protons (APs) are the protons extracted from RCS after the main pulse. If these protons hit the production target, they may produce electrons via prompt processes in the measurement time window. These electrons may have the same momenta as the μ-e conversion electrons, thus they may become backgrounds as shown in Figure 2.

In principle, APs should be largely suppressed by two major RCS features. The first one is the large kicker angle of the extraction due to large ring aperture of the RCS ring, where it originally aims to avoid the radio-activation of the ring equipments. This suppresses the accidental extraction of protons in the ring when the kicker magnet for the extraction is off. The second one is the fast-extraction of protons from the ring, that extracts all protons in the ring to outside at once and does not leave any protons in the RCS ring after extraction.

3. AP Counter

It is noteworthy that APs are heavily suppressed as it was already explained above. However, it should be considered that protons may be scattered off by ring equipment. When it is postulated that AP ratio is $\sim 10^{-18}$, where the AP ratio is the ratio of the number of the protons delayed from the main pulse to the number of the protons in the main pulse, the background event rate due to AP is estimated to be ~ 0.04 events/year. This value is smaller than the other background sources, but it is not negligible component. It is very important to evaluate the number of AP by actual measurement.

According to a Monte Carlo simulation with G4beamline[2], the number of AP is proportional to the number of hits in a beam loss monitor (BLM) that is set up just beside the beam duct and behind the extraction kicker magnet of the RCS ring. The coefficient estimated by G4beamline is about 40. The first designed AP counter had two scintillation counters and an iron absorber between them. The thickness of absorber was 10 cm, and that of scintillators was 1 cm. This BLM was set up and the data were taken from 2012. The time spectrum of the coincidence hits from these two scintillation counters is shown in Figure 3. From this time spectrum, it was confirmed that the ratio of AP was less than 1.1×10^{-18} and the rate of background event was less than 0.04 per 2×10^{7} sec of data taking.

It is obvious that the distribution of the hit number of after the main pulse is not flat and has some contributions from particle decay(s). The fit of an exponential curve with a constant term to the spectrum after the main pulse reveals that the life time of the curve is consistent with that of muon at rest. It implies that the signal-to-noise performance of the BLM can be improved if it can distinguish the delayed 3 GeV protons from muon-decay positrons of which energy is less than 52.8 MeV.

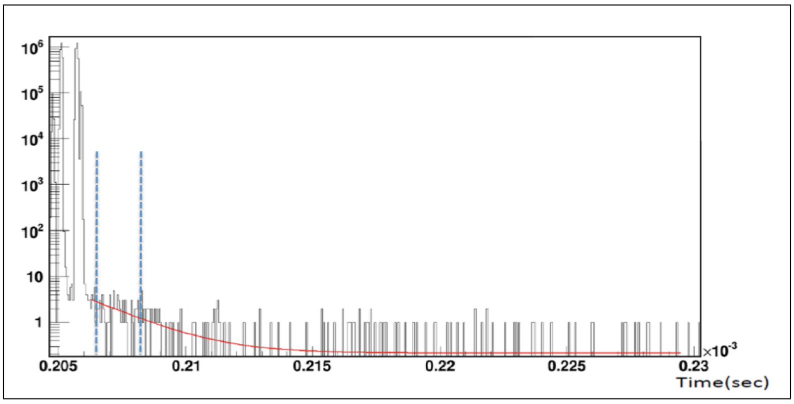

Figure 3: Time spectrum of hits to the 1st-generation AP counter. Two vertical dashed lines indicate the time region corresponding to the time window of electron measurement. A red curve is a result of function fit with an exponential curve and a constant term. The two peaks in the time range between 0.205 and 0.206 msec are the hits produced by the main protons.

4. Design of New AP Counter

In order to improve the particle identification performance of the BLM, a lead-scintillatorsandwich calorimeter structure is employed. The thickness and the number of layers for the scintillation counters and lead layers were optimized by using G4beamline with the 3 GeV proton beam and the 53 MeV positron beam. This simulation showed that the positrons stop in the BLM with producing electromagnetic shower and the most protons pass through the BLM and that it is possible to distinguish the positrons and protons by using the energy-deposit information from the scintillation counters. We found that the optimum configuration is the combination of 3 layers of 10-mm thick plastic scintillator, 2 layers of 16-mm thick lead and 2 additional outer layers of 32-mm thick lead as shown in Figure 4.

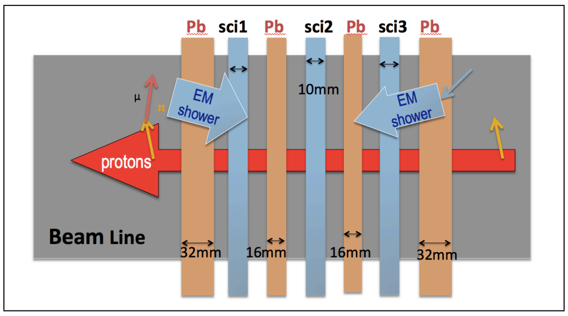

Figure 4: The concept of the new AP counter design.

The Monte Carlo calculation showed that energy deposit of positrons in each scintillator is less than 0.3 MeV in most events, and that of proton is more than 1 MeV. The positrons and the protons are distinguished with these energy deposit difference. The suppression factor of positrons is estimated to be less than 1×10^{-4} with the suitable selection threshold on the energy deposit as shown in Figure 5.

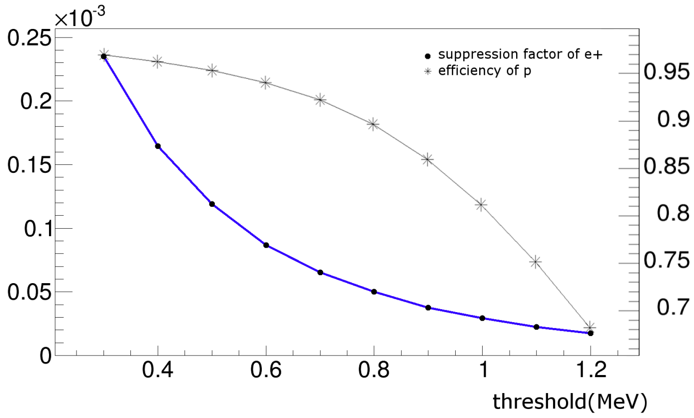

Figure 5: The suppression factor of e^+ with the left label and the efficiency of proton with the right label as a function of threshold of energy deposit.

5. Summary

DeeMe experiment requires the AP ratio to be less than 2×10^{-18} and it was confirmed that AP ratio is less than 1.1×10^{-18} by the first AP counter. The expected number of the AP background events with this AP ratio is small enough but it is not negligible. The new AP counter can suppress e^+ background by factor 10^{-4} and the AP ratio will be improved by two orders of magnitudes. This BLM is already installed in RCS tunnel.

References

[1] Y. Nakatsugawa, PoS(NUFACT2014) 093 (2014)

[2] G4beamline - http://www.muonsinternal.com/muons3/G4beamline