MEASUREMENTS OF PROTON BEAM EXTINCTION OF J-PARC MR SYNCHROTRON

K. Yoshimura*, Y. Hashimoto, Y. Igarashi, H. Nishiguchi, S. Mihara, KEK, Ibaraki 305-0801 JAPAN
M. Aoki, N. Nakadozono, T. Tachimoto, Osaka University, Osaka 560-0043 JAPAN

Abstract

Proton beam extinction, defined as a ratio of the residual and the pulse beam intensity, is one of the key requirements to realize the future muon electron conversion experiment (COMET) proposed at J-PARC. Measurement of the pulse timing structure with enough sensitivity is the first step to achieve the required extinction level of 10^{-9}. We have developed two methods for the measurements; one with fast-extracted beam and the other using secondary beam produced by slow-resonant-extracted beam. This paper describes the schemes and preparation status. These measurements would provide important information on the beam pulse structure to understand not only for MR beam but also the whole accelerator complex, including LINAC and booster RCS.

INTRODUCTION

A new experimental search for coherent muon to electron transition (COMET) was proposed as an experiment using J-PARC main ring (MR) beam[1]. The experiment requires 8 GeV slow-extracted bunched beam with spacing of $\sim 1\mu$sec. To achieve required beam, the various acceleration schemes has been studied[2]. For example, Fig. 1 shows one of such schemes which could be realized in ordinary acceleration with existing J-PARC accelerator elements. The RCS is operated at harmonics 2 and only one bucket is filled by using rf chopper. Then RCS beam (including the empty bucket) is injected to the MR four times. As a result, the MR beam is filled in every other rf buckets, i.e. four out of nine buckets. It is noted that if the beam chopping is not enough, LINAC beam is injected to RCS empty bucket and then transferred into the MR empty bucket as a residual beam.

The "extinction factor", which is defined as an ratio of inter-bunch residual and the main beam, is one of the most critical requirements for the COMET experiment to reach designed sensitivity. As shown in Fig. 2, search for a μ-e conversion signal is performed during the delayed timing window to eliminate prompt background caused by various products of proton-target interaction. However, if off-timing proton come around the timing window, it could create the background which may fall into the signal window. According to the detailed background study, the required extinction factor is less than 10^{-9} so that the designed sensitivity, i.e. 10^{-16} could be achieved.

Several accelerator studies were performed at BNL/AGS for MECO experiment and their measurements showed

* koji.yoshimura@kek.jp

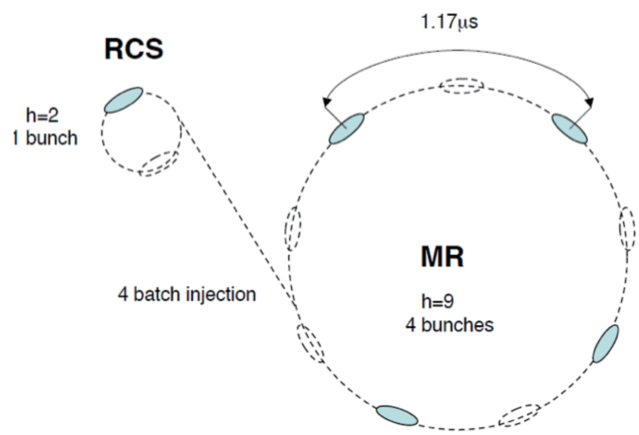

Figure 1: Simplest scheme of MR Injection for COMET experiment.

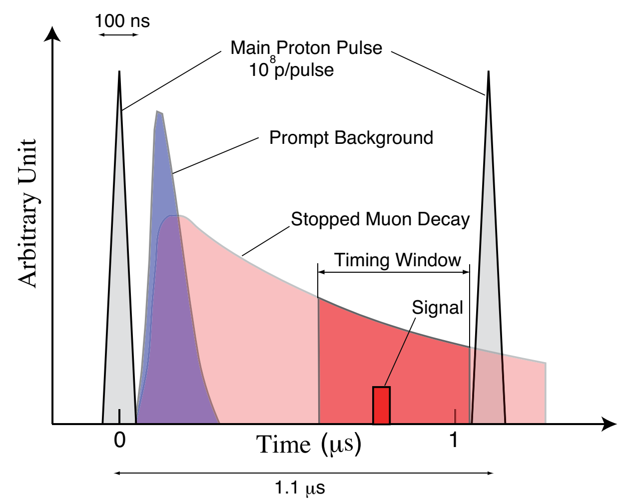

Figure 2: Required timing structure for the COMET experiment.

beam leakage into adjacent empty bucket during acceleration. Since then, extensive R&D works have been done to develop sweeping devices to eliminate residual beam both in MR beam and extracted beam. The actual actions to improve extinction, however, strongly depend on the the mechanism of deteriorating extinction. Therefore, we should clarify where and how proton leakage may occur by measuring extinction factor at J-PARC.

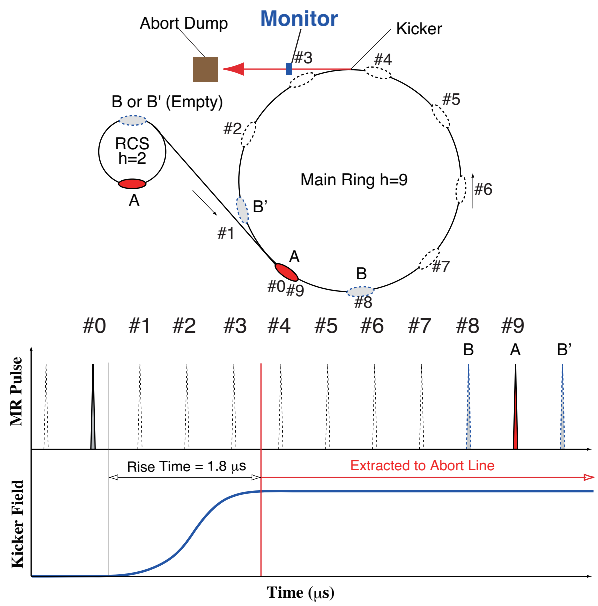

Figure 3: Fast extraction method.

MEASUREMENTS OF BEAM EXTINCTION

Measurement of beam extinction by level of 10^{-9} requires technical challenge to a detector which are capable of large dynamic range (10^9) and good timing resolution ($\sim$10 ns). R&D works are now in progress to develop gating device, such as gating PMT, which could screen main beam pulse within the gate window.

We alternatively discuss the following two methods:

- Fast extraction method:

  MR beam is fast-extracted and analysed with the external beam monitor. Separation of main pulse and inter-bunch beam can be done by adjusting kicker timing. This method can probe RCS bunch structure, beam leakage during acceleration and extraction.

- Secondary beam method:

  Slow-extracted beam is transported to the production target in the experimental hall and secondary beam produced in the proton-target collision is utilized to analyse the timing structure of the primary beam. This method can measure extinction under realistic condition, i.e. including beam leak during slow-extraction although it requires long measurement period.

Fast Extraction Method

Figure 3 schematically shows fast extraction method. The measurement is performed as follows:

1. Single bunch (A) is injected to the main ring at position #0.
2. Kicker starts to turn on just after passing through main pulse at #0.
3. Beam starts to extract from timing between #3 and #4 due to slow kicker rise time (1.8μsec).
4. All beam (one turn) after #4 are extracted and analysed with the beam monitor located between the kicker and the abort dump.

When main pulse is extracted (#9), the detector would be saturated and become insensitive due to the beam related secondary or scattered particles from beam the pipe and from the abort dump. So we could only investigate the beam structure from #4 through #8. If a faster-rise time kicker could be available in future,beam at #1 could be analysed.

In the measurement, position #8 is especially important. As shown in Fig. 3, we can change the order of the injection we can change the order of injection, i.e. which bucket of RCS is injected first. If empty bucket is injected first, B→A, empty bucket is located at position #8. In this case, empty bucket is extracted and analysed before main pulse, which gives the information about proton leakage at RCS. On the other hand, if filled bucket is injected first, A→B', then we could investigate the bucket which was not injected from RCS, which gives the information about leakage during acceleration inside the MR.

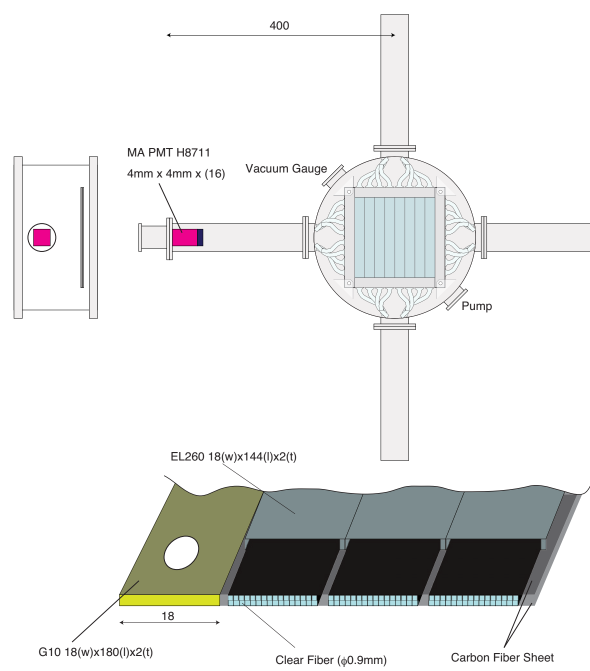

Figure 4: Beam monitor for abort line measurement.

We have developed a new detector for this beam measurement to meet the following requirements:

- $\sim$ 10 ns timing resolution with $\sim$ μs full scale to see the beam pulse structure.
- Gain can be adjustable by 5 order of magnitude.

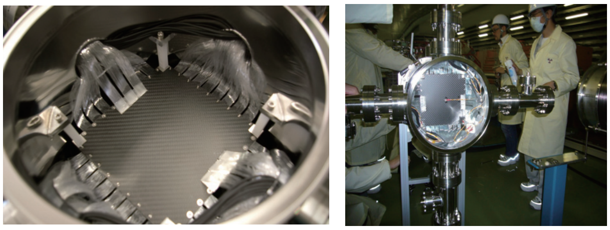

Figure 5: Photos of the beam monitor

- Cover beam size $\sim \phi 150$ mm
- Low material for radiation safety ($< 0.5\%$ loss)

Fig.4-5 shows the drawings and photos of the detector. The detector is two layer of 8 segmented hodoscope which comprise with thin scintillators and quartz bars, each paddle of which has 18(w)x2(t)x144(l) mm^3. Paddles were located along x and y direction, which is perpendicular to the beam axis. Light signals from both end of each paddle are guided through clear-fiber light-guide and led to Multi-anode photomultiplier (MA PMT Hamamatsu H8711). The PMT signals are read by 250 MHz FADC system based on KEK copper system.

Two types of scintillator (EJ200, EJ260) and fused quartz cherenkov counter will be tested in terms of radiation hardness and response to the background.

Fabrication of the detector has completed and tested by using cosmic-ray and LED light pulsar. The detector will be installed in this spring and perform measurement soon.

Secondary Beam Method

When the proton beam is bombarded to the production target, the secondary produced beam is expected to have similar time structure to primary pulse if we can carefully select the secondary beam to eliminate delayed component. We proposed to perform this type of measurement at K1.8 BR beam line where the first nuclear experiment (E15/E17) will be performed[3].

Figure 6 shows the layout of the hadron experimental hall located in the down stream of the slow-extracted beam line. We requested bunched proton pulse with 8 GeV. There are three sets of the hodoscope which will be used for E15/E17. Together with tof counter at the distance of 10 m from the 3rd hodoscope, we could clearly identify 1.0 GeV/c pion by beam counters and reject late arriving particles. DC separator can be used to eliminate kaon beam which could create background.

The pion yield is expected to be 50 K per main pulse (4×10^{11} proton). One day data taking could achieve the sensitivity level of 10^{-9}.

SUMMARY

We have proposed two methods which are complementary to investigate the pulse structure of MR beam. Preparation for the fast extraction method has completed and we would have the opportunity to measure the MR pulse structure for the first time soon. As for secondary beam method, we have studied and optimize configuration of the beam counters. These measurements are the first step to realize COMET experiment and we keep these activities to improve J-PARC accelerator performance in future.

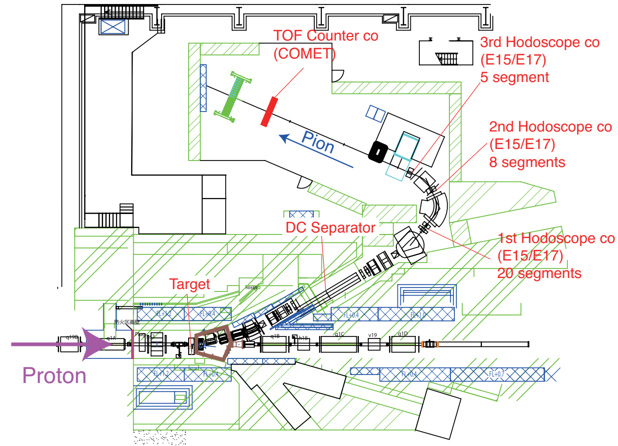

Figure 6: Beam line layout for secondary beam methods at Hadron experimental hall.

REFERENCES

[1] Y. Kuno *et. al*, "An Experimental Search for Lepton Flavor Violating μ^--e^- Conversion at Sensitivity of 10^{-16} with a Slow-Extracted Bunched Proton Beam", An Experimental Proposal on Nuclear and Particle Physics Experiments at the J-PARC 50 GeV Proton Synchrotron, November 30th, 2007, `http://j-parc.jp/NuclPart/pac_0801/pdf/Kuno.pdf`

[2] M. Tomizawa, *et. al*, "J-PARC ACCELERATOR SCHEME FOR MUON CONVERSION SEARCH", Proceedings of EPAC08, Genoa, Italy, 2008. pp 367–369.

[3] M. Aoki *et. al*, "Porposal for Extinction Measurement of J-PARC Proton Beam at K1.8BR", An Experimental Proposal on Nuclear and Particle Physics Experiments at the J-PARC 50 GeV Proton Synchrotron, October 17th, 2008, `http://j-parc.jp/NuclPart/pac_0810/pdf/Mihara.pdf`