J-PARC ACCELERATOR SCHEME FOR MUON TO ELECTRON CONVERSION SEARCH

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Abstract

The searching for coherent neutrino-less conversion of a muon to an electron (COMET) at sensitivity of 10^{-16} has been proposed as an experiment using the J-PARC Nuclear and Particle Experimental (NP) Hall. The experiment is planned to utilize a 56 kW, 8 GeV-bunched proton beam slowly extracted from the J-PARC main ring. The 1 MHz beam pulsing with an extremely low bunch to bunch gap background is needed to eliminate beam-related background events and keep an experimental sensitivity as high as possible. The 8 GeV-extraction energy is rather lower than an ordinary energy. The beam size must be less than apertures of the extracted orbit in the ring and the transport line to the NP Hall. Accelerator scheme to satisfy above requirements has been proposed.

INTRODUCTION

After cancel of The MECO experiment, the searching experiment for coherent neutrino-less conversion of a muon to an electron (COMET) at sensitivity of 10^{-16} has been proposed [1]. This proposal utilizes primary proton beam delivered from the J-PARC MR to the Nuclear and Particle Experimental (NP) Hall. Schematic drawing of the production target, pion capture section, pion-decay, muon transport and detector system are shown in Figure 1.

To achieve a sensitivity of 10^{-16} in the branching ratio of μ^--e^- conversion, 10^{18} muons is necessary. Assuming that the running time 2×10^7 s, 56 kW beam power is needed. An energy of primary proton beam is chosen to be around 8 GeV in order to suppress a production of unti-protons.

Pulse width of proton beam is 100 ns and space between the beam pulses should be 1μs (see Figure 2). It is very important to distinguish emitted electron signals and background. Residual protons in between the proton pulses produce the beam related background in the electron signal timing. In order to suppress such a background up to a permitted level, the beam extinction defined as a ratio of the residual and the pulse beam intensity should be less than 10^{-9}. A summary of the requirements for the proton beam is listed in Table 1.

A bunched slow extraction scheme to satisfy above requirements is presented in this paper.

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Table 1: Proton beam requirement for COMET

Beam Power	56 kW
Energy	8 GeV
Beam Current	7 μA
Beam Emittance	~10π mm·mrad
Bunch to Bunch Gap	1 μs
Bunch width	100 ns
Beam Extinction	10^{-9}

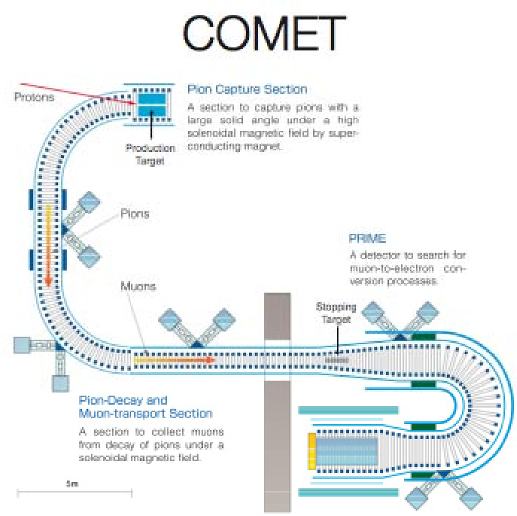

Figure 1: Schematic layout of the muon beam line and detector system of COMET experiment.

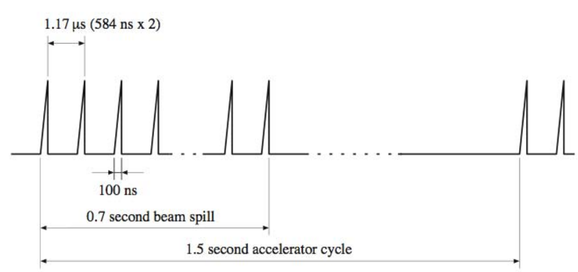

Figure 2: Required time structure of proton beam.

BEAM PULSING

The J-PARC accelerator complex comprises a 400 MeV linac, a 3 GeV rapid cycle synchrotron (RCS) and a 50 GeV main ring (MR) [2].

In the ordinary operation of the accelerators, the RCS

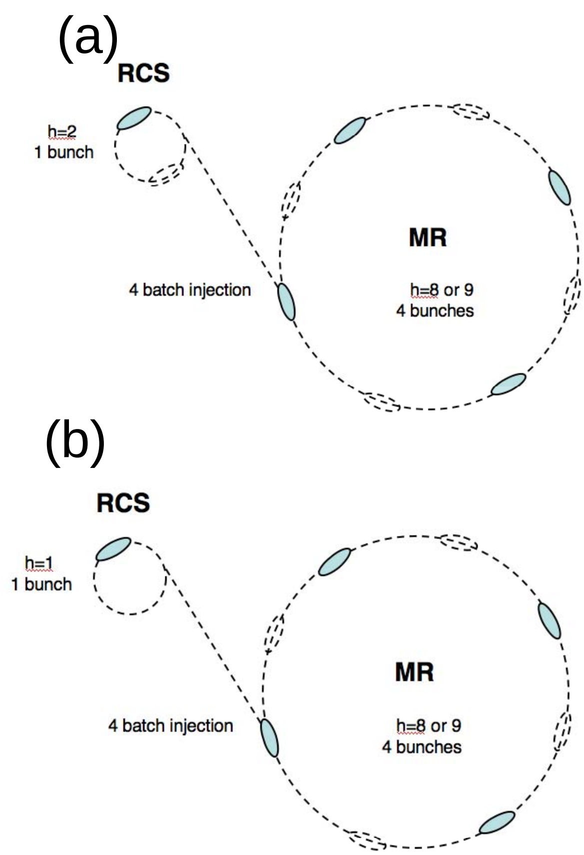

Figure 3: MR Injection Scheme.

accelerates 2 beam bunches at harmonic 2 and the MR 8 bunches at harmonic 9 (f=1.67MHz). This case, bunch to bunch spacing of the MR beam is about 300 ns, which does not satisfy the requirement. We have proposed the following three schemes.

(1) The RCS is operated at harmonics 2. However, the beam bunch number in the ring is single. This is achieved by operating at half repetition period of the rf chopper placed between the RFQ and the DTL. Since this doubles a duty factor of the rf chopper, feasibility should be carefully checked. The MR is operated at harmonics 9 or 8. The RCS beam is injected to the MR four times every 40 ms. As a result, The MR beam is filled in every other rf buckets as shown in Figure 3 (a). In this scheme, if the beam chopping is not enough, residual beam is kept in empty buckets of the RCS and the MR. This would worsen the beam extinction.

(2) The RCS is operated at harmonics 1, and the MR is at harmonic 9 or 8 as shown in Figure 3 (b). This is achieved by operating the rf chopper at the same repetition as the above (1). However, a duty factor of the rf chopper is smaller than that the scheme (1). In this scheme, the RCS does not have any empty bucket. It is preferable from the beam extinction point of view. The RCS rf frequency becomes half than original one. The present broadband rf system would need a minor modification. There is a possibility that the residual beam generated in the MR is trapped in the MR empty buckets.

(3) The RCS is operated at harmonics 1, and the MR is at harmonics 4. This seems to be an ultimate scheme from the beam extinction point of view. However, the MR rf frequency becomes half, it is unknown that how we modify the present rf system. In this scheme, the bunch length becomes longer. We may need an rf manipulation to obtain acceptable bunch length.

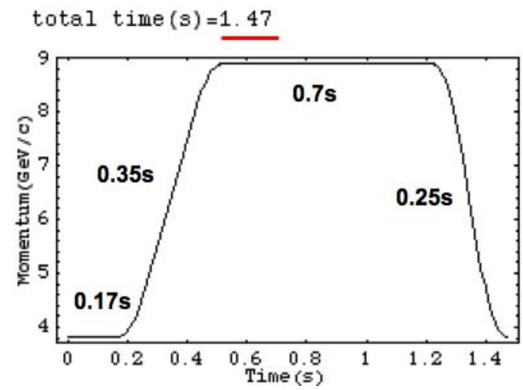

Figure 4: Probable MR pattern for 8 GeV slow extraction.

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ACCELERATION PATTERN AND EMITTANCE CONTROL

A probable MR acceleration pattern at the 8 GeV slow extraction is shown in Figure 4. The beam is injected 4 times every 40 ms from the RCS to the MR. The acceleration gradient is same as that of the 40 GeV standard pattern. The necessary rf voltage is 210 kV. The flat top time for the slow extraction is assumed to be 0.7s, which is for the oridinary operation. But this period may be reduced further. Total acceleration period is 1.47 s. The 1.6×10^{13} ppb × 4 bunches corresponds to 56 kW at 8 GeV. The particle number per bunch is 1/2.6 of that for 750 kW design.

The septa apertures for the slow extraction have been determined from the beam with 10π mm·mrad emittance at 30 GeV energy. This case, we suppose 144π mm·mrad painting area at the 400 MeV RCS injection, and emittance growth factor of 2.25 through the RCS and the MR. At 8 GeV energy, the emittance is 4 times larger by less adiabatic dumping effect. To solve this problem, we

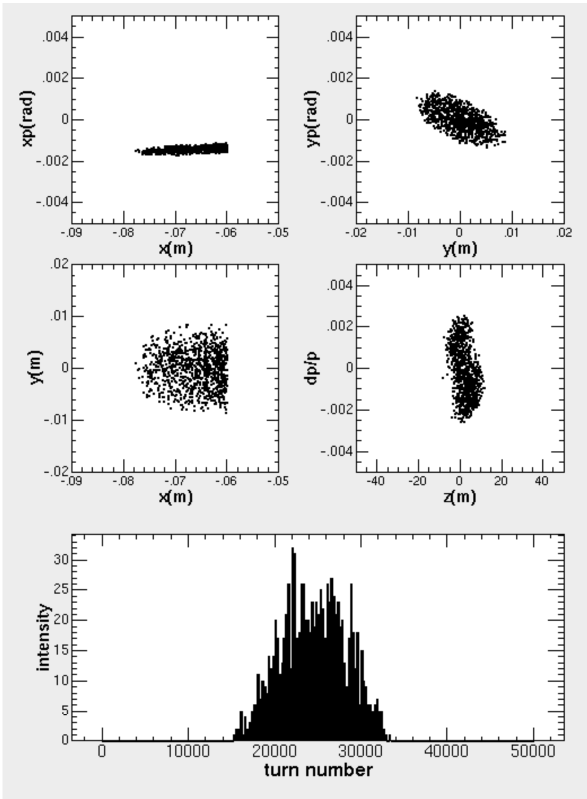

Figure 5: Simulation of bunched slow extaction.

propose that the painting area of the RCS injection is reduced at 90-100π smaller than 144π.

SLOW EXTRACTION

The J-PARC slow extraction uses the third integer (67/3) resonance [3]. The 116.1 m long straight section, where electrostatic, magnetic septa and bump magnets are placed, has zero dispersion. When the horizontal chromaticity sets near zero, chromatic extraction can be possible. Ordinary experiments require coasting extracted beam. In this case, the rf voltage is ON during extraction to keep bunch structure. We have simulated the bunched extraction process. The extraction energy is 8 GeV. The horizontal and vertical emittances of circulating beam are 10π mm·mrad. The rf voltage is 210 kV with harmonic 9 and longitudinal beam has 3eV•s emittance and is matched in the rf bucket. The horizontal tune is approached from below to above by ramping 48 QFN quadrupoles in arc section. The quadrupole ramping speed is rather high in this simulation, as a result, obtained spill time is 0.1s, which corresponds to 13 times of a synchrotron period. Figure 3 shows the extracted beam distribution at the entrance of the first electrostatic septum. The simulation shows the bunch structure is kept during extraction process. In this condition, the bunch full width is roughly 50 ns.

BEAM EXTINCTION DEVICE

In order to achieve 10^{-9} extinction, we have a plan to introduce a beam sweeping device (external extinction device) comprises a kicker and collimator placed in the external beam line from the MR to the NP hall. The design is now in progress in the collaborations with FNAL and TRIUMF under Japan-U.S. Science and Technology Cooperation Program. When the external extinction device can not achieve the required extinction, we need beam sweeping in the MR (internal extinction device). We here mention the following three candidates as the internal extinction device.

(1) The AGS scheme uses a vertical AC dipole and a kicker [4]. The AC dipole field excites betatron resonance. On the other hands, the kicker is fired just during beam bunches to compensate the kick by the AC dipole. Thus residual beam in bunch to bunch space can be swept out. This scheme has been successfully demonstrated using AGS beam.

(2) A rf knockout field gated in only bunch-bunch spacing can sweep out residual beam.

(3) Sweep out by just kicker. Beam manipulation is simple, but it needs a larger kick angle for the kicker.

CONCLUSIONS

We have proposed the accelerator scheme for μ^--e^- conversion experiment. This scheme can deliver 1 MHz-pulsed beam over about several hundreds of ms for the COMET experiment.

The following issues will be studied from now on;

- Effect of the particles scattered at the electrostatic septum on the beam extinction
- Space charge effect on slow extraction process at the 8 GeV.

The beam extinction measurement of the MR is planned in the MR run from coming December by recently formed muon working group. This would give an important information for harmonics choice of the RCS and the MR and design of the extinction devices.

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