COMET Task Force Report II

COMET Task Force
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Abstract

We describe recent activities of the COMET task force.

1 Introduction

The COMET proton beam requirement is summarized in Table 1. The time structure of the proton beam has to be pulsed in order to suppress the beam related background that will mostly come at prompt timing. The ratio of the number of residual protons in between the pulses to that of protons in a pulse is called a beam extinction and should be reduced to 10^{-9} or less to achieve the proposed sensitivity of the experiment. In order to realize this requirement, proposed schemes of proton acceleration[1] have been discussed in this task force with help of accelerator experts. In parallel the task force has been working on developing a measurement technique of the beam extinction with a better sensitivity than ever achieved. Recently we have conducted

Table 1: Pulsed Proton Beam for the COMET experiment.

Beam Power	56 kW
Energy	8 GeV
Average Current	7 μA
Beam Emittance	10π mm·mrad
Protons per Bunch	$< 10^{11}$
Extinction	10^{-9}
Bunch Separation	1 μsec
Bunch Length	100 nsec

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a test using a newly developed monitor installed in the main ring. The result indicates that there is proton contamination in the bucket that should be empty, which will cause deterioration of the beam extinction.

Extraction of the proton beam from the main ring needs to be done without destroying the time structure of the beam. Due to this, COMET requires to do beam extraction with a method called bunched slow extraction. This is, in principle, same with the normal slow extraction but with keeping the acceleration RF voltage on during extraction. Measurement of the beam extinction with bunched slow extraction[3] is planned to be done probably at 30GeV in 2009 and at 8GeV later. We expect that this will clarify all existing problems concerning the beam extinction.

We reported in the previous meeting [4] a possible optics of proton beam transport including external extinction devices between the accelerator and experimental hall. We are currently developing an AC-dipole magnet to improve the beam extinction in the proton transport line. Conductor R&D is in progress in a US-Japan cooperation research program [5].

Possible layout of the experiment has been discussed in the task force, too. Recently consideration of the possibility is actively ongoing in JPNC[6] taking into account the schedule of whole program of proposed experiments using the J-PARC main ring beam. Detailed design of the experimental area will be carried out in coming years with design work of the proton transport line and beam dump. R&D work on solenoid magnets has been started by the collaboration. The task force is contributing to this work from various aspects.

In this report recent studies of the task force are described for proton beam acceleration in Section 2, for the proton beam extinction in Section 3, for proton beam extraction and transport in Section 4, for the experimental space in Section 5 and for solenoid magnets in Section 6. In the last section we will describe the future prospect of task force activities.

2 Proton Beam Acceleration

We are studying proton beam acceleration schemes based on the design described in the proposal. Empty buckets as shown in Figure 1 are necessary for realizing the COMET beam time structure shown in Figure 2.

Accelerator operation with empty buckets can be realized by utilizing the chopper [1] in the linac system. The chopper kicks out the micro bunch from the RFQ accelerator as illustrated in Figure 3. Particles are not accelerated when the chopper is activated. The performance of the chopper will be described later from the view point of the beam extinction, but here we mention that efficiency of beam scraping is found not to be sufficient for the CEOMET experiment. This means that we need additional device to clean empty buckets. One possible method we are discussing is to use the pre-chopper installed in the linac system. This is an energy modulation type pre-chopper installed in an induction cavity (see Figure 4 [7]) located between

[1] There are currently two chopper cavities installed in series.

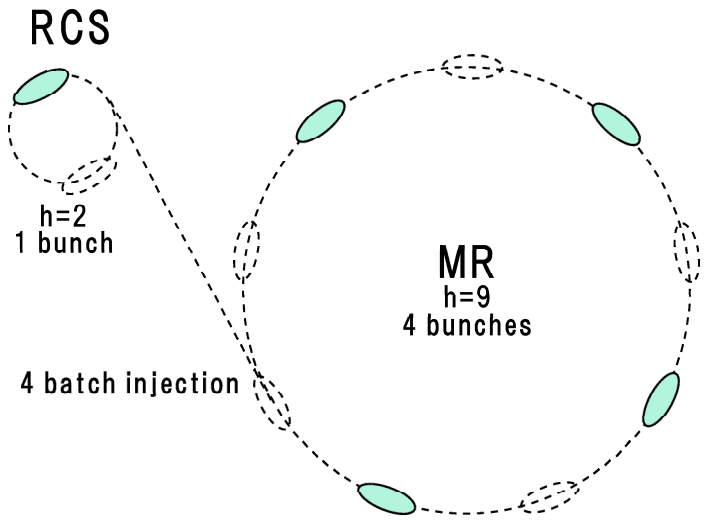

Figure 1: Machine cycle structure of the baseline method.

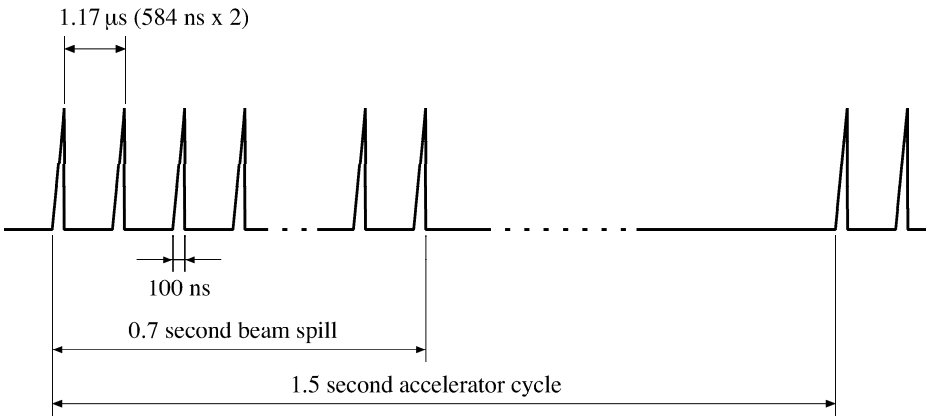

Figure 2: Bunched proton beam in a slow extraction mode.

the ion source and RFQ. Protons whose energy reduced below a threshold at 42–43 keV cannot transmit through the RFQ. Thus it is expected that operation of the pre-chopper to shape the COMET bunch structure will provide additional suppression of remaining protons in empty buckets. The device has been installed to help beam pulsing without causing higher load in the chopper scraper at higher current operation than 50mA. However the device is not operational currently due to noise dispersion from it. We expect that the device is very useful to improve the beam extinction since beam pulsing is done at earlier stage of acceleration. The lower the beam energy is, the better the beam separation can be achieved. We would like to request strongly the accelerator group to settle down the noise of the pre-chopper and make it operational in reasonable time. Although it might not be equivalent, we can test effectiveness of the pre-chopper by simulating the situation with operation of the ion source at lower voltage.

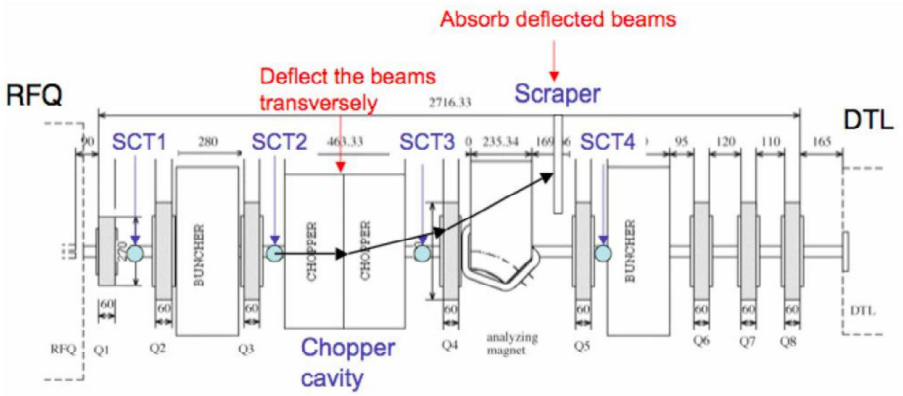

Figure 3: Overview of the chopper system.

Concerning the acceleration scheme, recently another bunch configuration is considered additionally. That uses 3 buckets in the MR with keeping remaining 6 buckets empty. Proton beam power will be reduced 3/4 while in this case bunch-to-bunch length will be about1.5μsec and we can extend measurement period. Feasibility of the experiment needs to be investigated by the COMET group. Accelerator operation itself is possible in spite of the fact that RCS bucket filing will be slightly complicated.

3 Extinction

As described in the previous report [4], we are investigating the beam extinction at J-PARC main ring from two different approaches. One is an approach trying to see directly the proton beam using a newly developed monitor installed in the main ring abort line. The other is a measurement of proton time structure extracted to the experimental hall, where we measure secondary particles produced by the primary (pulsed) protons and investigate the beam extinction by integrating the measurement in terms of time.

Recently measurement at the abort line was carried out and we obtained preliminary result of the beam extinction. The layout around the abort line is shown in Figure 5. We installed a monitor in the abort line as shown in Figure 6 and a plastic scintillation counter outside the beam duct. The scintillation counter is called an outside counter, measuring scattered particles by the monitor in the beam duct.

The study was done with filling only one RCS bucket. Particles to be filled in the other RCS bucket were scraped by the linac chopper. Both buckets are transfered to the main ring, accelerated to 30GeV, and then kicked to the abort line. Order of the filled and empty buckets were controlled depending on the intended measurement but in almost all cases bunches are configured so that the empty bucket is extracted earlier than the filled bucket. Figure 7 shows waveforms of the abort line monitor and outside counter for bunch configurations of empty-filled buckets extraction (left) and filled-empty buckets extraction (right). The empty (filled) bucket is extracted

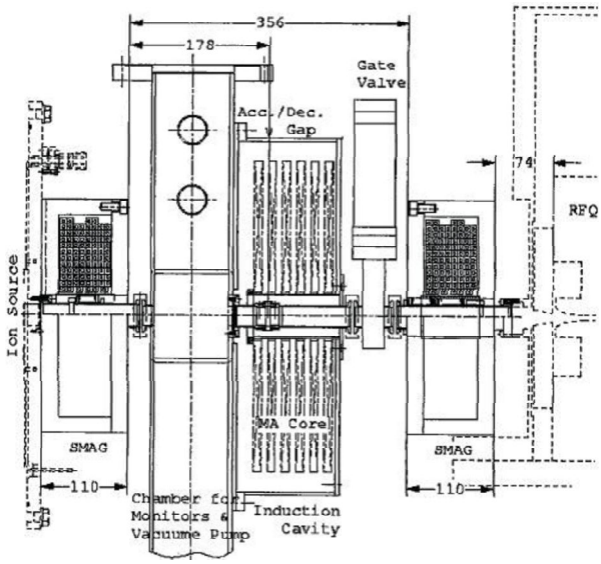

Figure 4: Schematic drawing of LEBT [7]

earlier than the other in empty-filled (filled-empty) buckets extraction. The abort line monitor signal was input to the channel 2 and the outside counter signal was to the channel 4. The abort line monitor was operated with much lower gain than nominal PMT operation by applying only 300V while the outside counter was operated at usual PMT gain around 10^{5-6}. It can be seen that there are small pulses in front of the large pulses in both counters. They arrived earlier than the large pulses by exactly same time with bunch-to-bunch separation length. They are probably caused by remaining protons in the empty bucket where all protons from the linac should have been scraped away by the chopper. This means that inefficiency of the chopper system is not negligible and the beam extinction is deteriorated due to this.

The number of protons remaining in the empty bucket is estimated as follows. We reduced the number of protons in a bucket by controlling the chopping width at the linac chopper, and the number of intermediate bunched (N_{ib}) to be filled in the RCS. The number of protons in a bucket is proportional to N_{ib}, thus we can estimate the number of protons at lower intensity by scaling down the number of protons measured at higher intensity where usual accelerator monitors are available. When we reduced the chopping width to 12.4nsec and took a configuration of N_{ib}=47, we measured the number of proton in a filled bucket of 8×10^8 with the conventional accelerator monitor. Then we reduced N_{ib} step by step and observed almost same amount of protons each in filled and empty buckets at the abort line monitor when N_{ib}=1. This indicates that there are remaining protons in the empty bucket of $8\times10^8/47=1.7\times10^7$. The number of protons at full intensity is known to be 4×10^{11}, thus we estimate the beam extinction at this moment to be $1.7\times10^7/4\times10^{11}=4\times10^{-5}$.

By using the abort line monitor signal, which has been proved to be the most sensitive monitor at J-PARC accelerators, we tried to optimize the phase of the chopper RF phase relative to the linac micro-bunch phase (324MHz) in order to

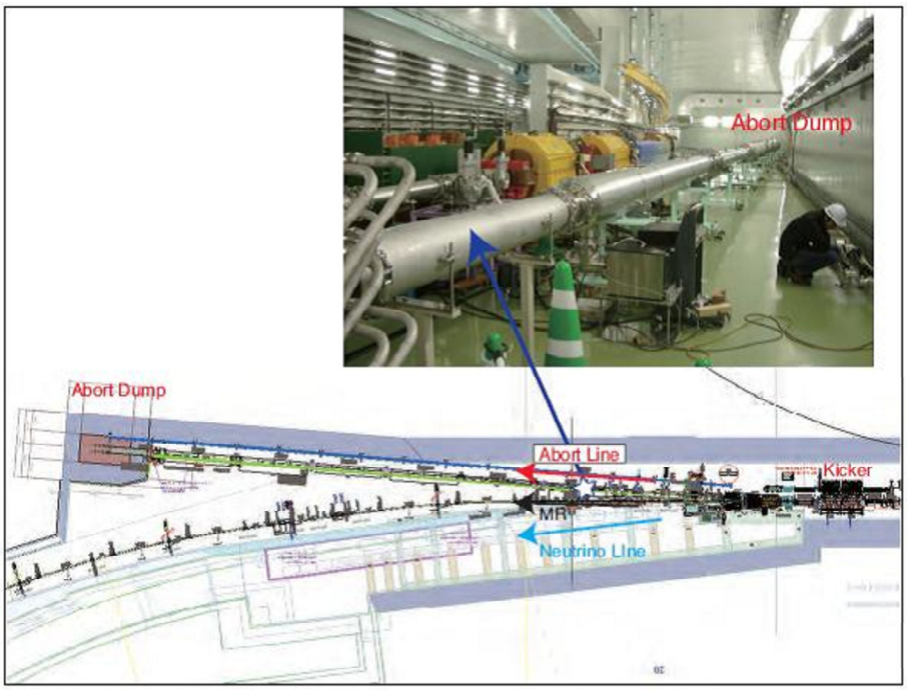

Figure 5: Layout of the abort line and extinction monitor

improve the chopping efficiency. Figure 8 shows the pulse height of the abort line monitor for the empty bucket as a function of the chopper phase difference from its original setting. It can be seen that we can improve the chopping efficiency by a factor of 2.5 by setting the phase difference at 16 degree. This provides additional improvement of the extinction by a factor of 2.5 [2], resulting in the beam extinction of 2×10^{-5}. The chopper consists of two cavities, but currently both are driven by a single power supply. If these can be operated with two independent power supplies, it is possible to adjust the phases of the RF voltage independently and to improve proton beam pulsing. This will certainly provide further suppression of remaining protons in an empty bucket.

Further study was done by increasing the sensitivity of the abort line monitor to investigate the area where any bucket was not transfered from the RCS. We applied higher voltage on the PMTs and performed the measurement again. Figure 9 shows waveforms of the abort line monitor together with the outside counter. The dotted line overlaid on the waveforms shows a kicker excitation timing. We observed some particles in the area indicated by an arrow although no particle should appear in that area since no bucket was transfered from the RCS. Evaluation of contribution of these particles to the beam extinction is in progress. However, we expect that this contribution is small enough judging from the pulse hight and rough evaluation of

[2]In this measurement the scintillator suffered from saturation effect since too many particles hit single scintillator bar at once. Because of this the monitor response is thought to be in a non-linear region and the actual reduction factor is expected to be better than 2.5. Detailed analysis is in progress.

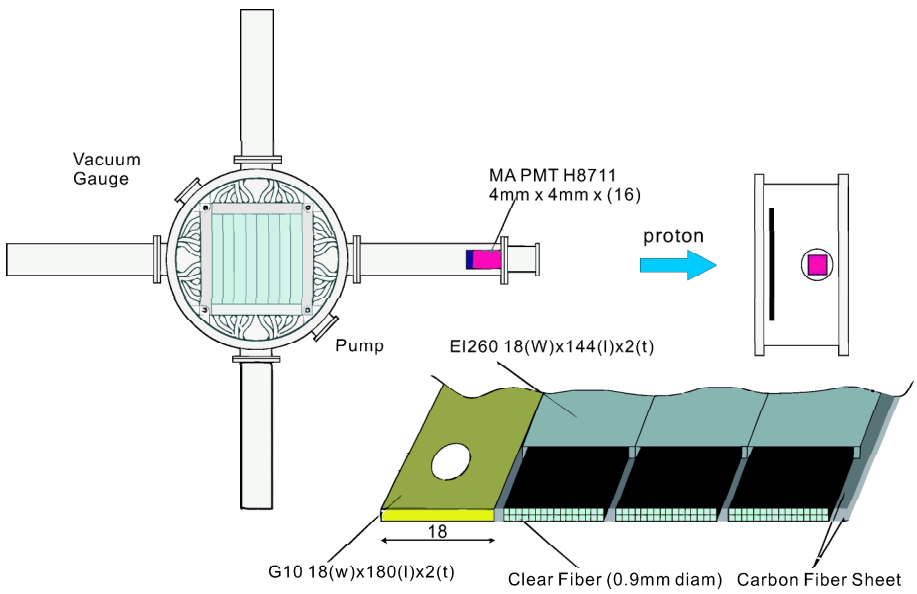

Figure 6: Schematic view of the abort line monitor

the PMT gain including the effect of attenuation of the signal cable as long as 300m. Those particle are thought to have leaked from the filled bucket in the accelerator.

A similar measurement was performed with installing a FWPM (Flying Wire Profile Monitor) in the main ring at the flat top in order to investigate how material sitting on the proton trajectory affects the beam extinction. Protons are usually extracted at this flat top period after acceleration is completed. Figure 10 shows the result. We observed large PMT signal in the region where there should not be any particles. We guess that scattered particles by the wire were coasting in the ring and extracted by the kicker to the abort line. It is not exactly the same situation, but this suggests that some protons hitting the electro-static septum foil during slow extraction can behave in a similar way. If such particles would be coasting in the ring

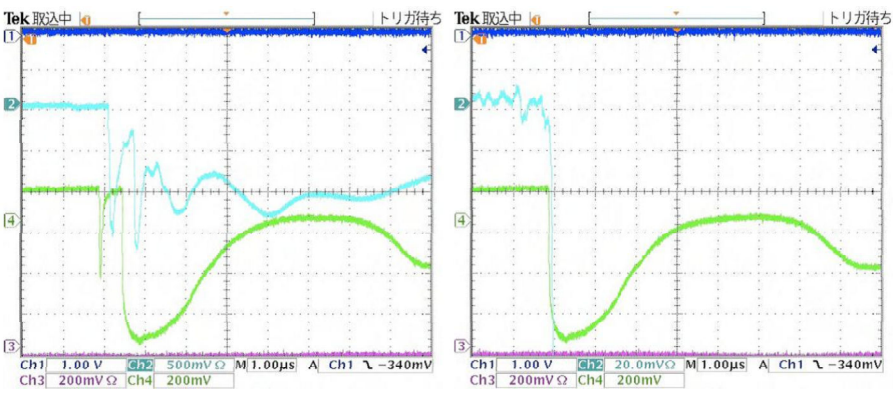

Figure 7: Waveforms of the abort line monitor and outside counter

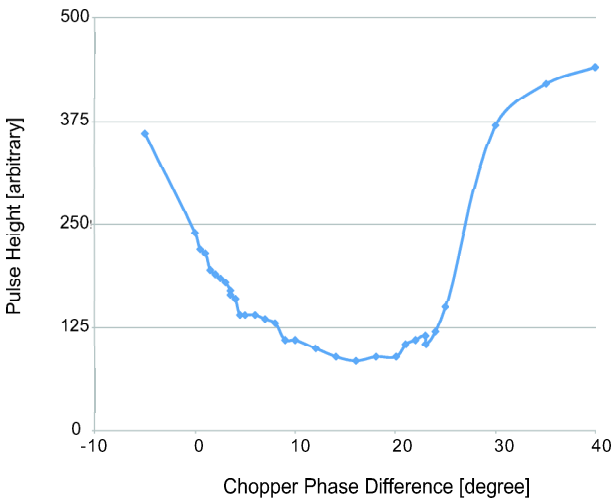

Figure 8: Number of protons in an empty bucket as a function of chopper RF phase difference from the original setting.

and extracted eventually together with the core part of the beam, this may cause significant deterioration of the beam extinction. To clarify this problem we stress the importance of the measurement of the beam extinction at a secondary beam line with bunched slow extraction and request to do this measurement when the accelerator operation is stabilized in this year.

4 Proton Beam Extraction/Transport

The pulsed proton beam in the main ring has to be extracted to the experimental hall without destroying its pulse (time) structure. This is realized by the bunched slow extraction method, which utilizes devices for slow extraction such as an electro-static septum installed in the main ring. Acceleration RF voltage should continue to be applied so that the pulse structure can be maintained during extraction. As described in Section 3, it is found that any material, even if it is very thin, on the proton beam trajectory in the main ring can cause particle leakage from an RF bucket. This will result in deterioration of the beam extinction. The electro-static septum has a thin foil for scraping the beam and some particles can directly hit the foil while extraction. Of course the situation is different from the case of FWPM because the foil is off the beam profile, however we believe that it is very important to investigate the effect by performing the bunched slow extraction. When we conduct this test, the extracted beam will be monitored in a secondary beam line by measuring the time structure relative to the RF timing as described in [3]. Abort line monitor used in the previous study should be operated at the same time to watch the situation in the main ring.

We reported possible configuration of the proton transport line including external extinction devices (AC dipoles and an collimator in between them) in the previous

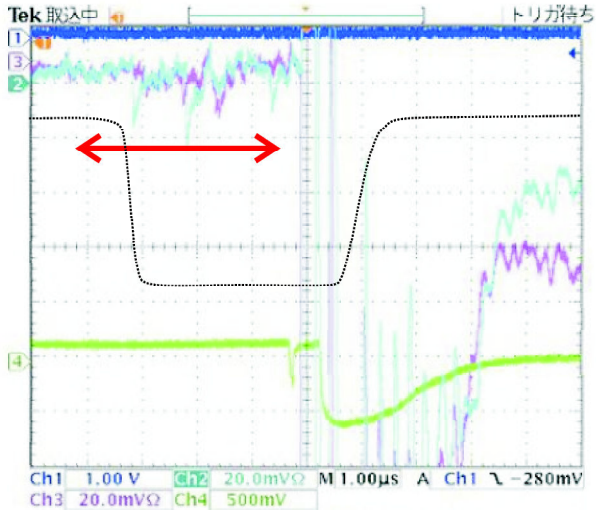

Figure 9: Waveforms of the abort line monitor with nominal voltage on its PMTs and outside counter

report [4]. R&D work on the AC dipole is in progress in the collaboration. Prototype study of the AC dipole conductor is being done in a US-Japan cooperation research program [5].

Detailed design of the transport line will be done after the experimental layout is fixed. The transport line will be shared with the high-momentum beam line that will be constructed in near future and thus the line is requested to be able to transport 30GeV proton beam.

5 Experimental Space

Space in the experimental hall for the COMET has been one of main issues to be discussed in the task force. Recently JPNC (J-PARC Particle and Nuclear Physics Coordination committee) has been formed and the layout in the experimental hall is a subject of considerable discussion. Figure 11 shows a planned layout in JPNC. The whole setup of the COMET experiment will be located outside the experimental hall together with the pion/muon production target and beam dump.

6 Solenoid Magnet

Magnet R&D is in progress with the collaboration. Details are described in the COMET CDR [8]. In this year we will investigate aluminum for stabilizer. We plan to test three different kinds of aluminum currently available. These have different additives; Ni, Mg+Cu, and Y. We plan to measure basic parameters of these aluminum such as the residual resistance ratio (RRR) and mechanical strength. In parallel we are going to produce a super-conducting wire of 200m length in order to study basic

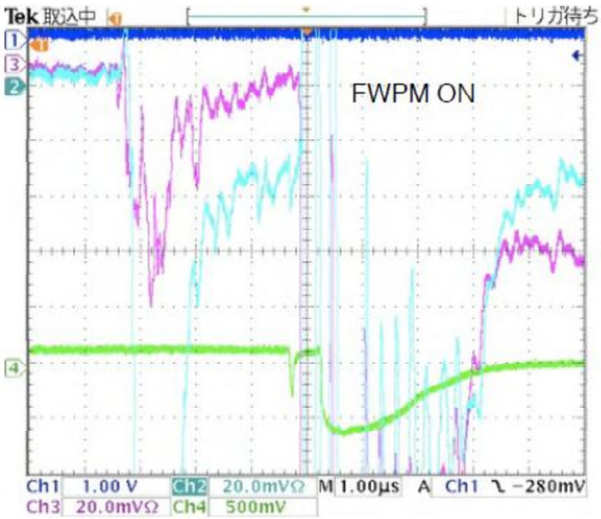

Figure 10: Waveforms of the abort line monitor with nominal voltage on its PMTs and outside counter. The FWPM was installed at the flat top in the main ring.

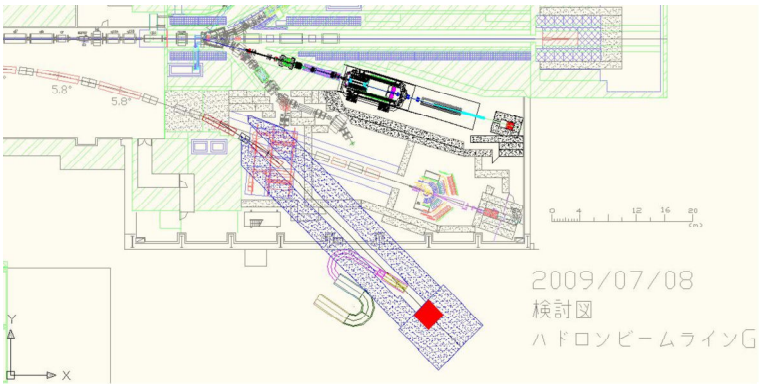

Figure 11: Layout of the COMET experiment in the experimental hall.

manufacturing process. Several tests are planned to investigate wire characteristics such as adhesive strength between the conductor and aluminum stabilizer.

Cooling performance and electromagnetic forces for the curved solenoid is under study by using a prototype comprising of three pancake coils as reported in the CDR[8].

7 Summary and Prospects

The task force has been working actively to study issues to realize the COMET experiment in a reasonable time scale. Recently the first measurement of the beam extinction at the main ring abort line was carried out and preliminary result is presented in this report. We have found that there are remaining protons in an empty

bucket that could not be eliminated by the linac chopper. We estimated the number of remaining protons to correspond to the beam extinction of 2×10^{-5}. It is obviously important to improve this. Operating the pre-chopper, which is already installed in the linac system, is expected to improve this.

As was demonstrated by installing the FWPM in the measurement, any kind of material staying on the proton beam trajectory possibly cause deterioration of the beam extinction. The foil of the electro-static septum might affect the proton beam time structure, producing coasting protons in the main ring during extraction. In order to have a first look on this effect, we plan to do another measurement using secondary beams produced by protons extracted from the main ring with the bunched slow extraction.

We expect that the situation will be improved by installing additional devices to improve the extinction on the proton beam transport line between the main ring and the experimental hall. Development of an AC dipole magnet is in progress as a device for this purpose. Possibility to use different kind of external extinction devices is also investigated.

The acceleration scheme for realizing the COMET beam will be able to be tested when we perform the extinction measurement using the secondary beams. In this sense the measurement will be an integrated test of necessary accelerator components to realize the COMET proton beam time structure.

Layout of the COMET experimental space is agreed in JPNC and will be published soon. The collaboration will start engineering design to construct the proton beam line and experimental area with help of the facility and beam channel groups.

R&D work on the super-conducting solenoid magnet will proceed with the COMET collaboration. Selection of aluminum stabilizer will be done in a test using different samples with different additives. At the end of this year, we will obtain a conductor sample with which we will study basic procedure of manufacturing process and also perform several tests to investigate wire characteristics. Engineering design of infrastructure such as a magnet power supply, cooling water, helium refrigerator should be taken into account when the experimental area is designed.

The task force will continue to work more, especially on proton acceleration for the experiment and intermediate region between the facility and experiment. For this purpose we have called on new members to the task force from the J-PARC accelerator group and collaboration. We believe that this is certainly helpful for setting up the necessary environment of the COMET experiment in a timely manner.

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