COMET Task Force Report I

COMET Task Force

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Abstract

We summarize activity of the COMET task force. This is the 1st report of the group and should be regarded as an intermediate report. The final report is prepared after the extinction measurement completes.

1 Introduction

It was suggested to form a task force for the COMET experiment in the 4th J-PARC PAC meeting as follows. "If possible a task force should be set up to consider the special demands of the required beam structure, energy, and intensity." In response to this, the task force has been formed by convening experts in the fields of accelerator, super-conducting magnet, beam line, and experimental hall, and physicists from the COMET group. The goal of the task force has been discussed by the members ourselves and is defined, "In order to realize the experiment that can provide significant physics result, the task force aims at showing a realistic solution(s) for the experiment under discussion among experts from accelerator, beam channel, and physics groups." Tasks have been defined later in order to archive this goal. They are

- Proton beam acceleration
- Extinction
- Proton beam extraction/transportation
- Experimental area

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These issues have been discussed among task force members. In this report we will show possible solutions obtained in these discussions for some of them and/or address propostions that will necessary to be proved by experiments for the others.

2 Proton beam acceleration

As we have stressed many times, the success of the COMET experiment hinges on the quality of proton beam to produce pions/muons. The proton beam must be pulsed and the purity – extinction – must be sufficiently good as described in the proposal [1]. In the proposal three acceleration methods are presented as summarized in Table 1.

Table 1: J-PARC MR bunching scheme. N_h is the number of RF harmonics, N_b is the number of filled bunches.

Method	RCS		MR		Difficulty	Extinction	Note
	N_h	N_b	N_h	N_b			
(I)	2	1	9	4	Easy	Bucket Leak (RCS, MR)	Heat Load
(II)	1	1	9	4	Moderate	Bucket Leak (MR)	
(III)	1	1	4	4	Higher	Good	Major Work

The method (I) is the simplest one that can be realized without any hardware modification in the J-PARC accelerator chain. Thus we concluded that all kind of preceding tests should be done in this scheme. A possible problem contained in this method is that protons can be trapped in the empty bucket in the RCS when it is operated for providing protons to the main ring (MR) and that empty bucket is transferred to the MR without any change. In this case apparently the extinction level is deteriorated. Proton leakage to the empty bucket in the RCS can be caused by overshoot at the chopper scraper in the LINAC. In this sense the method (II) is better since the RCS beam is not affected by the performance of the chopper scraper although we need a minor modification of the hardware. A drawback of this method is longer pulse width due to modification of the RF frequency of the RCS. However if the pulse length is acceptable for the experiment, this method should be emphasized as a balanced solution in terms of performance and necessary cost. The method (III) is ideal because there is no empty bucket anywhere, resulting in no proton capture outside the buckets. Of curse there is possibility for protons to escape from the RF separatrix as illustrated in Fig.1 [1] However such protons cannot stay in the accelerator and are swept out after a few turns in the ring. Thus they are not to contribute to deteriorate the extinction at a crucial level to the COMET experiment. Difficulties to realize this method comes from the fact that we need to modify the harmonics number of the MR. This indicates that (almost) complete replacement of the RF

[1] We need a full understanding of the accelerator parameters such as noise level of RF and exact shape of the beam in the phase space to evaluate the probability of leakage.

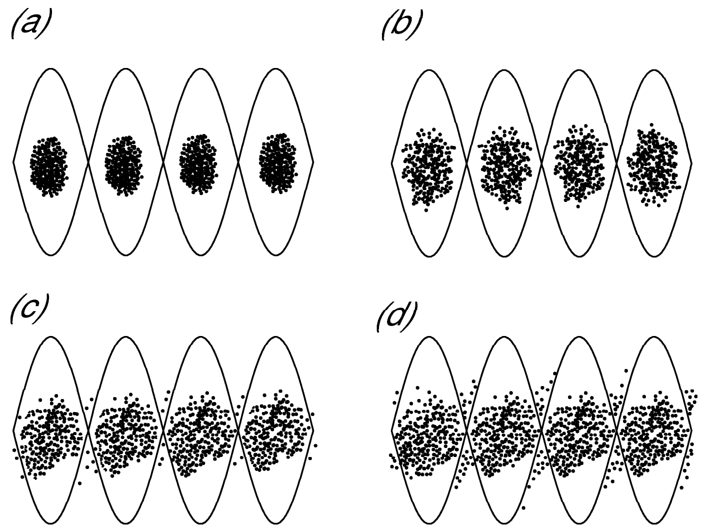

Figure 1: Illustration to show how particles can escape from buckets in the phase space where it is supposed that the RF harmonics number is 4 with all buckets filled.

cavities in the MR is necessary, which is obviously not a trivial thing, from the view point of MR operation schedule. Changing the main harmonics number is equivalent to produce new cavities according to the RF group and we would like to leave this option not to be emphasized until we fail to reduce the extinction level by employing all methods considered by now.

As already reported in 6th J-PARC PAC meeting, we propose to start a systematic study of the extinction by employing the method (I) and establish the measurement technique. After that we can compare two methods (I) and (II) with measurement data.

It will be beneficial to study the growth of beam structure by a simplified simulation. Especially studying the beam purity development will be useful in future when we try to improve the extinction in the MR. Evaluating contributing factors of each to deteriorate the extinction will be perhaps useful in order to improve the extinction systematically. Of course to simulate such behavior will require complete understanding of the accelerator.

3 Extinction

Which extinction level we can measure and achieve will determine how small branching ratio we can reach in the experiment. As we have emphasized, it is necessary to develop both methods to improve and measure the extinction level in order to realize such an extreme requirement ($< 10^{-9}$ extinction) of the experiment. This development work is in progress under close collaboration between the task force and experiment group. The COMET group is developing monitoring device to be installed in the MR and/or proton transport line, and also an external extinction de-

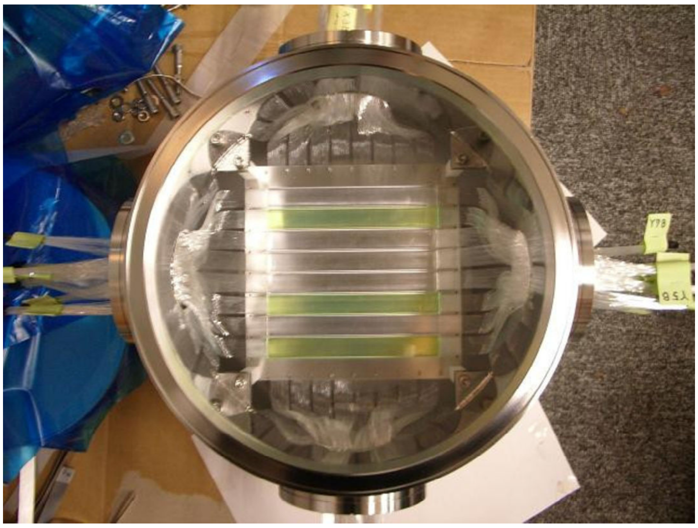

Figure 2: Abort line detector for extinction measurement. A layer of plastic scintillators can be seen with optical fibers to transfer scintillation light to photomultipliers. View along the proton beam line.

vice, so-called AC-dipole, in order to improve the extinction level after proton beam is extracted from the accelerator.

The task force has been concentrating on establishing methods to measure the extinction level down to a sufficiently low level. As explained in the report [2], we are developing two methods to have an initial look on the extinction level in J-PARC accelerator. One is a monitor installed in the abort line of the main ring and is intended to measure directly the proton beam in the MR. The other is a method using secondary beam provided at K1.8BR as proposed in the 6th PAC meeting [3].

Measurement at the abort line will be done when the accelerator is operated in a single-bunch mode with low intensity ($< 4\times10^{11}$/bunch). The detector consists of two layers. The 1st layer consists of 8 thin plastic scintillators viewed by two multi-anode photomultipliers through optical fibers and the 2nd layer is made of an array of quarts slabs, which are much stronger against radiation damage than plastic scintillator. The quarts layer is also read by multi-anode photomultipliers through optical fibers. Fig.2 shows a photo of the setup. Evacuation test has been completed and we have confirmed that outgassing is in the tolerable range to be installed in the MR. The device is ready to be installed in the abort line at the beginning of March 2009.

Prior to this study, we studied photomultiplier signal by using a scintillation counter during the MR operation period in February 2009. The counter is a simple plastic scintillation counter with photomultiplier readout. That is located at the same position where the abort line monitor will be installed (but outside the beam pipe). The distance to the abort line dump is about 60m. We used the signal cable (300m length) to be used for the abort line monitor to investigate the signal quality at the counting room on the ground. Fig.3 shows the counter installed in the abort

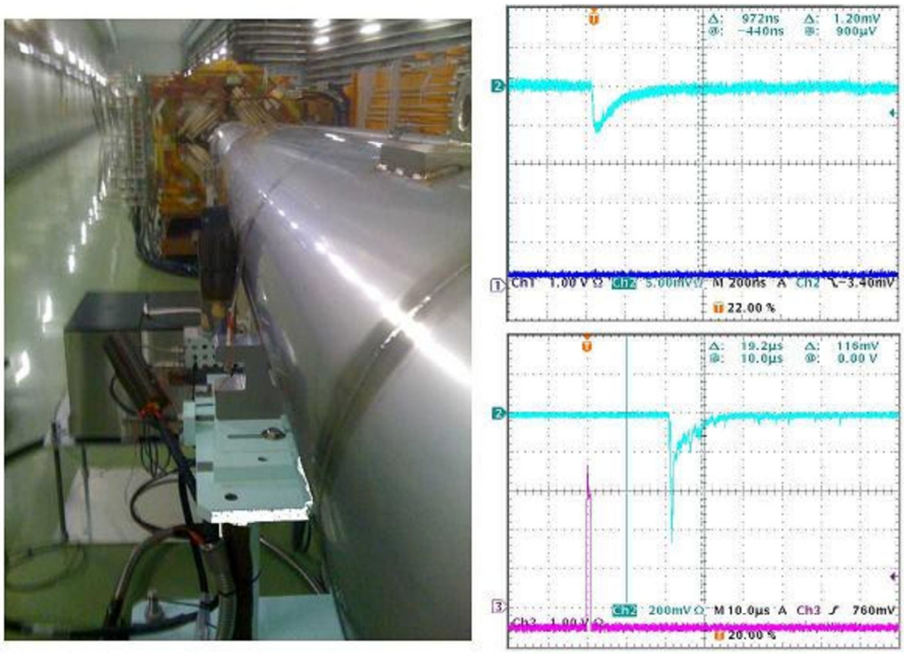

Figure 3: Plastic scintillation counter installed in the abort line (left). Typical photomultiplier signal for cosmic ray without beam in the MR observed at the counting room through a 300m cable (right top) and signal observed when the beam was dumped to the abort line (ch 2) and kicker timing signal (ch 3) (right bottom).

line and typical photomultiplier signals observed at the counting room through a 300m cable. The right-top figure shows a photomultiplier signal for cosmic ray without beam in the MR and the right-bottom figure shows a signal when the beam was dumped to the abort line. The sharp pulse seen on the channel 3 is a timing signal for excitation of the abort line kicker. It can be seen that some particles arrived at the counter 20μsec after that timing signal and continued for about 20μsec. In addition late arriving particles continued to hit the counter even for about 10msec. Since this counter is located outside the beam pipe, the counter itself is sensitive only for loss in the MR or any kind of secondary particles produced at the dump. However we did not see any particle signal and/or noise before that, which suggests a possibility of clean measurement with the abort line monitor. Fig.4 shows the photomultiplier signal observed during proton acceleration (180msec later after the start of acceleration) it the MR. The RF timing signal is also shown. We observed signal synchronized with the RF timing. Of course these must be caused by loss in the MR, but from this measurement we confirmed that measurement using photomultipliers is feasible for time structure study of the primary proton beam.

Concerning the measurement at K1.8BR, we plan to execute this measurement in collaboration with the COMET and E17 groups after beam line setup completes for the E17 experiment. During accelerator operation period with slow extraction in

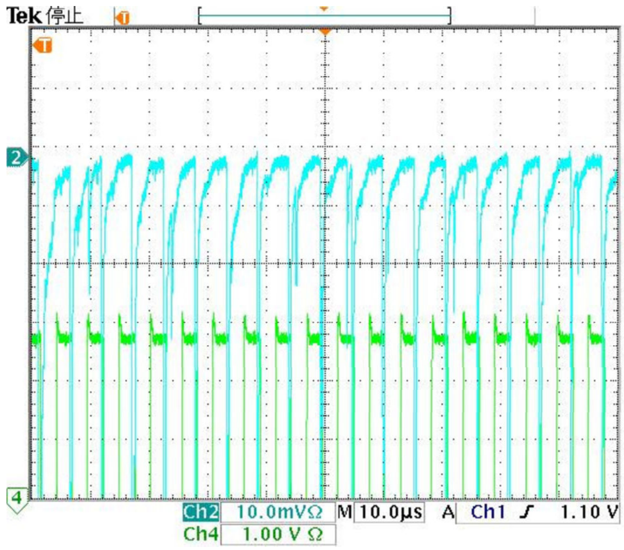

Figure 4: Photomultiplier signal during slow extraction. RF timing signal is also show.

February 2008, the E17 and beam channel groups succeeded to transport 1.0GeV/c beam to the end of the K1.8BR beam line. Some more work needs to be done to complete fine tuning of the beam line apparatus, which is expected in the year 2009. Note that this extinction study at the K1.8BR beam line uses pulsed secondary beam generated by proton beam with bunched slow extraction (realized by performing normal slow extraction without switching off the RF voltage after acceleration). This extraction mode has been already tried at the beginning of the beam line setup in January 2009 and proved to work. [2]

AC-dipole and gas Cherenkov type counter R&D is in progress under the U.S./Japan cooperation research program[4]. Concerning the AC-dipole development FNAL is taking a responsibility of developing hardware and succeeded to produce the 1st prototype of the conductor. Simulation work is under way in Japan to fit the J-PARC primary beam line in the experimental hall. A design is shown in Fig. 5 together with simulation results of particle time structure before and after the AC-dipole section. It can be seen that improving factor of the extinction by the AC-dipole system is larger than three orders of magnitude.

4 Proton beam extraction/transportation

Proton beam extraction has been studied in simulation. This study intends to investigate the effect of extraction devices on the beam structure. An important issue here is whether we can keep the bunch structure during bunched slow extraction without

[2]This measurement can be performed even if the extraction stability is not guaranteed enough.

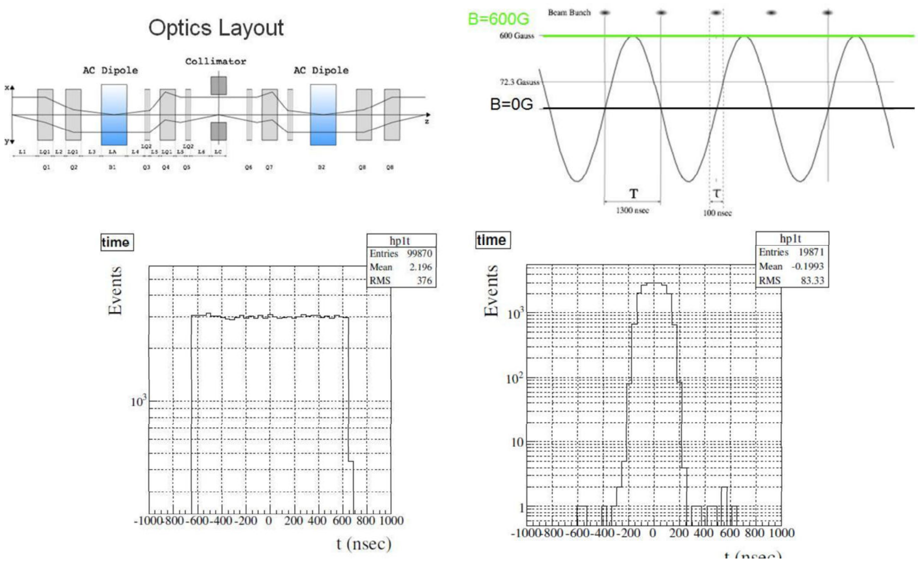

Figure 5: Optics layout of the AC-dipole section for J-PARC proton primary beam line (top left). Magnetic field of the magnet is changed as shown in (top right). Time distributions of the proton beam are shown in (bottom left) for an input in the simulation and in (bottom right) for the final focusing point where the pion production target is located.

producing any leakage from a bucket to neighboring empty buckets. It is also important to confirm that the bunch width can be kept within the requirement. Fig.6 shows a result of slow extraction simulation. It can be seen that the bunch width along the z axis (parallel to the beam) does not grow up even after extraction.

Another study to investigate the effect of a electro-static septum foil is in progress. It is known that a fraction of the proton beam (0.1∼0.2%) are scattered by the foil while in extraction. Such scattered proton will escape from the RF bucket and may be captured again by another (empty) bucket, resulting in deterioration of the extinction. Understanding this effect by simulation will be certainly of advantage when we will try to improve the extinction in future.

Transport simulation of the extracted proton beam is done by using the TRANSPORT and G4Beamline[5] programs. The beam line configuration consists of three major part as illustrated in Fig.7, matching section, AC-dipole section, and final focusing section. The design takes into account a possibility to transport 30GeV proton beam also to a planned primary beam experiments in the experimental hall.

In this simulation realistic proton beam parameters are taken into account as listed in Table 2. Fig. 8 shows the profile of the proton beam. The beam size at the pion production target is 1 mm in X and 3mm in Y both in sigma, which is sufficient to efficiently produce pions on 4cm diameter target of graphite. Recently the COMET group is considering to use a heavy metal target to gain the muon yield. In this case the target diameter needs to be smaller to maximize the muon yield. For example 2mm diameter will be an optimal for a tungsten target. To cope with such

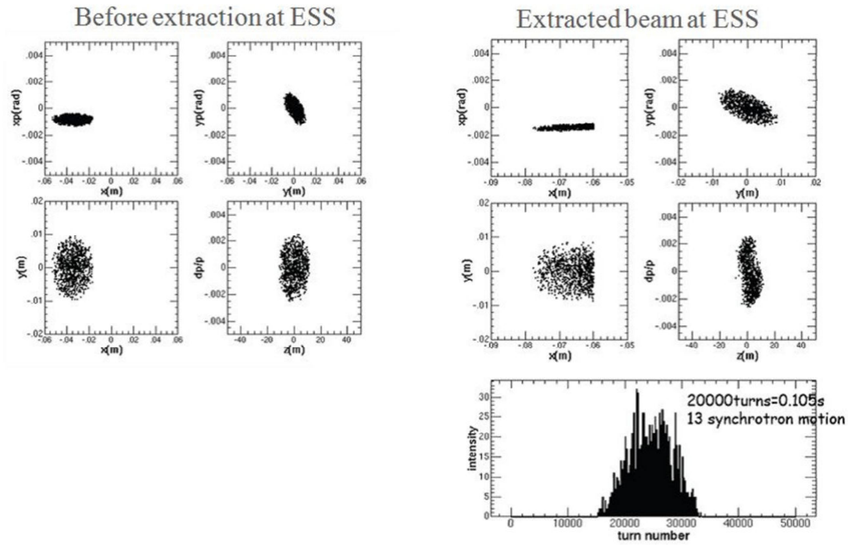

Figure 6: Particle profile in the phase space before and after extraction at ESS

requirement further optimization work of the beam transport is necessary.

One important remark in the design of the proton transport line is that the gap size of the AC-dipole may be a limiting factor. It is limited because larger gap size requires larger electric power for magnet operation. This must be carefully taken into account when we design the beam line.

5 Experimental area

A layout of the experiment must be carefully considered with taking into account radiation, infrastructure such as electricity and cooling water, and interference with other experiments. Radiation issue is the most critical one to launch the experiment.

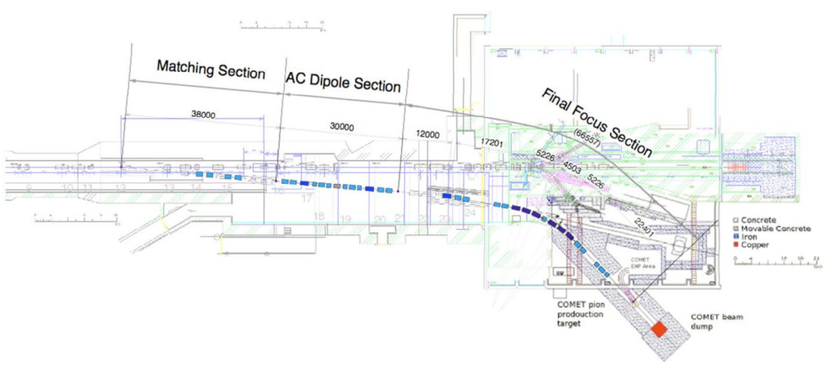

Figure 7: Layout of the beam line components used in the simulation.

Table 2: Beam transport simulation input parameters

Momentum mean	8888.9MeV/c
σ_X	10.0 mm
$\sigma_{X'}$	0.125×10^{-3} rad
σ_Y	1.5 mm
$\sigma_{Y'}$	1.66×10^{-3} rad
Momentum distribution	8888.9±26.7MeV/c (Flat)
Time distribution	±650nsec (Flat)

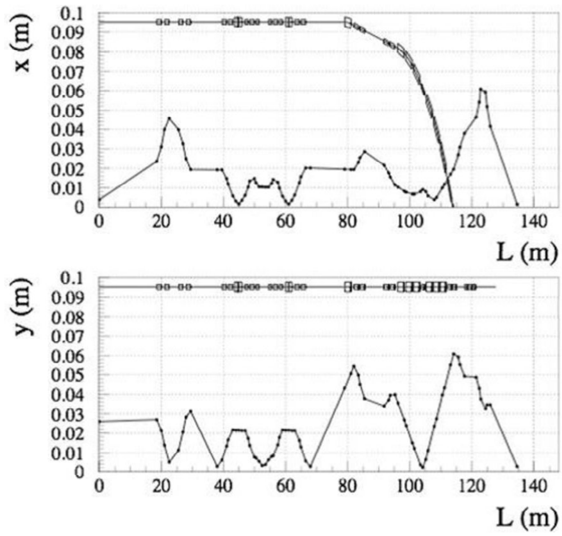

Figure 8: Transport calculation of primary proton beam.

Prompt radiation dose must be reduced below 5mSv/h on the outer surface of the radiation shield in the ground. For realizing this, it is necessary to place 5.5m thick concrete shielding material or corresponding underneath the target and beam dump (Fig. 9). It is also important to consider reusability of the space after the experiment. If the hall floor or space for the future extension of the hall were contaminated heavily by radioactivity, that would affect future program at J-PARC and must be avoided by any means. Thus it must be better to locate such apparatus outside the hall as long as J-PARC will be an useful device for coming decades after the COMET completes data acquisition.

Concerning other experiments, we expect that Kaon physics experiments planned to be executed in K1.1 beam lines will complete their data acquisition in the 1st phase of J-PARC. After that primary beam experiments including COMET will come in the hall and start construction. Those primary beam experiments might conflict with COMET in terms of the space. Requirements on the proton beam, especially intensity of the beam, are different between COMET and other experiments, which indicates

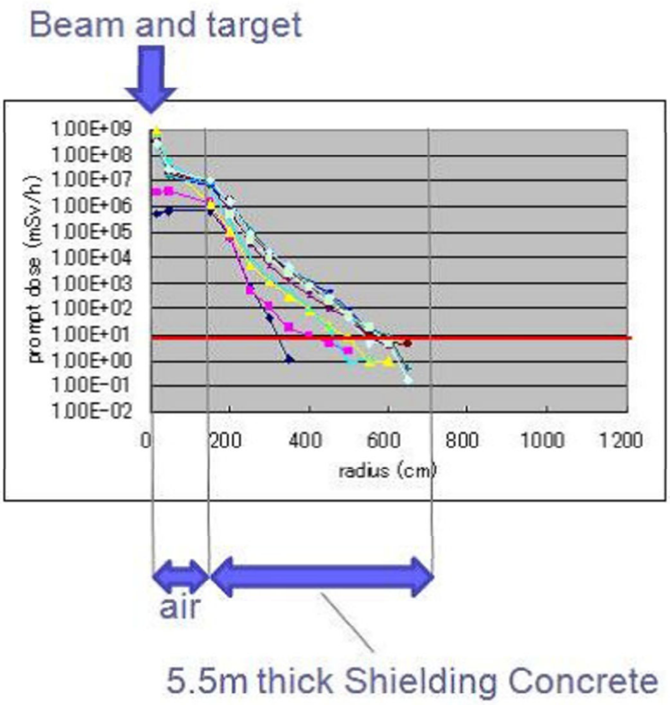

Figure 9: MARS calculation of the prompt dose as a function of the distance from the target. We suppose the proposed COMET target geometry and infinite thickness of floor concrete.

that sharing the whole beam line is difficult.

Consequently we have come to the conclusion that the target and beam dump should be located outside the experimental hall but they should not be located in the space for the future extension of the hall. A possible layout of the target and beam dump is shown in Fig.10 where muons can be transported to the muon stopping target located in the experimental hall followed by the detector. Another possibility is to locate the target and dump in the B-line switch yard and transport muons to the left side of the primary A-line over it where future possibility to build an experimental area has been discussed.

The power supply and refrigerator for the capture solenoid magnet are necessary to be placed near the magnet to reduce installation cost. The power supply should have a capability to supply 5000∼10000A 10V according to the current design of the magnet. The unit is as large as the power supply for super conducting bending magnets in the T2K proton beam line. The size of the power supply is 2m $\times$ 8m. Another unit will be necessary to supply current to the muon transport and detector solenoid magnets.

The capture solenoid magnet cooling requires relatively large power of about 100W using liquid helium since that must sustain superconductivity in hard radiation heat

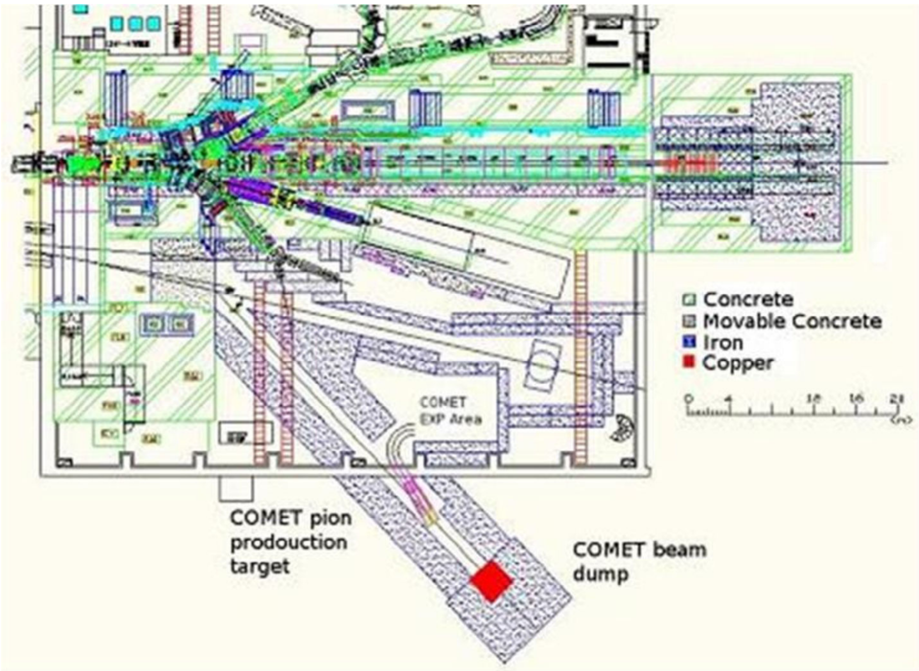

Figure 10: Possible layout of the COMET pion production target and beam dump. Muons can be transported to the muon stopping target located in the experimental hall together with the detector.

environment from the pion production target, while transport and detector solenoid magnet cooling can be managed by small refrigerators directly mounted on each of them. The cooling system for the capture solenoid will consist of a cold box (3m×3m), control dewar (3m×3m), and compressor (3m×2m). In addition to these, a buffer tank for helium recovery as large as 100m^3 and a liquid nitrogen storage need to be prepared for operation. Cooling water will be necessary for the system, too. Our current estimate of necessary cooling power is 500kW. If this cannot be managed by the cooling water system in the experimental hall, it is necessary to install a cooling tower dedicated to use for the COMET magnet system.

6 Summary

We reported recent activity of the COMET task force. The task force concentrated its activity on consideration of issues concerning proton beam acceleration, extinction measurement, proton beam extraction/transportation, and experimental area. Extinction measurement is the most important issue among them. An extinction measurement will be performed in 2009. The final report of the task force will be prepared after that measurement completes.

References

[1] Propsal to J-PARC 2007, The COMET collaboration. available at http://comet.phys.sci.osaka-u.ac.jp

[2] COMET Report submitted to the 5th J-PARC PAC meeting. available at http://research.kek.jp/people/mihara/COMET/PAC-2008/pac-2008.pdf

[3] Proposal to J-PARC 2008 submitted to the 6th J-PARC PAC. meeting available at http://research.kek.jp/people/mihara/COMET/PAC-2008-2/pac-2008-2.pdf

[4] U.S./Japan cooperation research program, "A New Initiative for Realization of Muon-Electron Conversion Experiment

[5] Muons, Inc. http://www.muonsinc.com/