A Letter of Intent to The J-PARC 50 GeV Proton Synchrotron Experiments

Request for A Pulsed Proton Beam Facility at J-PARC

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Abstract

With this Letter of Intent, we present physics motivations of selected programs of antiproton and pulsed muon beams, and a possible new facility layout for the pulsed proton beam. We will hope that the construction of such a facility at J-PARC starts at the earliest possible. We like to request special arrangement in the J-PARC phase-1 construction to avoid soil activation at the location of the future fast extraction port.

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Chapter 1

Executive Summary

Physics Motivation : With this Letter of Intent, we stress the importance of a pulsed proton beam facility at J-PARC. With such a facility, we could anticipate various significant physics programs, ranging from searches for lepton flavor violating muon rare processes, a search for the muon electric dipole moment, the precise measurement of the muon anomalous magnetic moment, to rich antiproton physics including precision spectroscopy of antimatter, ultra-slow antiproton sources, and nuclear physics with antiprotons. In a long term future, it would lead to an opportunity on construction of a neutrino factory in Japan. The highest beam power and high beam energy of 50 GeV at J-PARC would provide very unique opportunity, which is definitely superb over the other facilities in the world.

The Facility : The current plan of the experimental facilities of J-PARC does not unfortunately have any plan of a pulsed proton beam facility. The Nuclear and Particle experimental hall (NP-hall) currently planned will have only a continuous proton beam from slow extraction, and will not have a pulsed proton beam from fast extraction. The neutrino beam line, which will use a pulsed proton beam, can not accommodate any other experiments due to the space limitation. In the worldwide, requests of constructing a high intensity proton machine are rising, such as the upgrade MI (Main Injector) at Fermilab, the upgrade of AGS/BNL, SPL (Super Proton Linac) at CERN. For most of them, a pulsed proton beam is of primarily interest. Therefore, here, we would like to strongly request for a pulsed proton beam facility at the earliest possible so as to be competitive to the others.

Tentatively we are planning to identify a possible location of the pulsed proton beam facility to be nearby the beam abort dump of the 50-GeV PS. A preliminary layout is presented in this note. It consists of a near facility (close to the 50-GeV ring) and a far facility (beyond the public road), owing to the space limitation of the halls and the required beam line length.

Requested Arrangement at Phase-I : From the budget profile presently planned at J-PARC, the construction of the pulsed proton beam facility could be after Phase I. Even under this condition, at Phase I, we would like to ask the management of

J-PARC a special arrangement to avoid soil activation at the location of proton extraction port to a planned facility. Once soil is activated, future excavation would become almost impossible. To be more specific, **we would like to request placing concrete shielding blocks at the location of future extraction.** The details are given in this note.

In summary, a pulsed proton beam facility at J-PARC, once constructed, would give a unique opportunity to carry out significant physics programs with pulsed-muons and antiprotons, and hopefully a future step toward a neutrino factory. Those physics programs would have greatest discovery potentials, which should not be missed.

Chapter 2

Physics Overview

Some selected physics programs with antiprotons and muons, which could be achieved if a high-intensity pulsed proton beam is available, are presented.[1]

2.1 Antiproton Physics

The high intensity protons from the 50-GeV main ring of J-PARC are ideally suited for high-flux antiproton production. By adding a combination of cooler ring(s) and a decelerating linac, J-PARC can become the world center for low-energy antiproton physics, pioneered at CERN LEAR (Low Energy Antiproton Ring) and now being actively pursued at its successor AD (Antiproton Decelerator).

We realize that within the present J-PARC timeline, the physics using antiprotons is in Phase 2 or beyond, but it is critically important that antiproton capability will be included in the facility design at this stage. This is because a future antiproton facility would require a high-intensity fast-extracted beam, which cannot be easily shared with the neutrino beamline. Our joint-study with the 'PRISM' working group has shown that both a $\bar{\mathrm{p}}$ facility and PRISM can share a common beam line (with two sequential targets) and a beam dump.

2.1.1 Physics motivation

The main physics topics to be studied with low-energy antiprotons are i) precision spectroscopy for tests of fundamental symmetries (especially CPT), ii) atomic formation and atomic collision studies, iii) nuclear physics with antiprotons (investivation of nuclear periphery using antiprotonic atoms) and iv) gravitation of antimatter.

There are also proposals for more non-conventional applications of antiprotons, such as medical applications. In the US already two companies have been founded by employees of Fermilab to investigate these possibilities.

[1] Letters of intent on a search for muon-lepton-flavor-violating $\mu^-{-}e^-$ conversion process, a search for the muon electric dipole moment, and the precision measurement of the muon $g-2$ anomalous magnetic moment, are available.

No detailed proposals exists at the moment to measure the gravitation of antimatter, but using neutral antimatter like antihydrogen has the advantage over experiments with charged antiparticles that the electric force does not play a role, which in principle allows to increase the experimental sensitivity tremendously.

2.1.2 Precision spectroscopy for tests of CPT

The main topic at the AD is the formation and spectroscopy of neutral antimatter. For antiprotonic helium, this has been going on for several years, and our most precise laser spectroscopy measurement has determined the antiprotonic helium transition frequencies to the level of some 100 ppb. By comparing the experimental value to the most accurate 3-body QED calculations, a CPT test on the equality of proton and antiproton charge and mass of $|M_p - M_{\overline{p}}|/M_p \sim |Q_p + Q_{\overline{p}}|/Q_p < 6 \times 10^{-8}$ has been achieved. By developing a laser system with higher resolution and going to lower density by using a Radio Frequency Quadrupole Decelerator (RFQD) to further reduce the p energy from 5.3 MeV to $\sim$ 50 keV, we hope to increase the precision of this measurement by one order of magnitude or more.

Antihydrogen, the simplest neutral antimatter atom consisting of an antiproton and a positron which the ATHENA collaboration at CERN AD recently succeeded to produce abundantly, has the potential of reaching comparable or higher accuracy than other CPT tests. This is because hydrogen has been studied with highest precision in the last 100 years, and two of its properties, the 1S-2S transition frequency and the ground-state hyperfine splitting are among the most accurately measured quantities in physics. The possibility to extend the accuracy to 10^{-18} as advocated comes from the fact that the width of the 2S state is about 10^{-15}, and that it should be possible to split this line by 1/1000. This has, however, not even been achieved for hydrogen, so it is likely to take a long time to reach this goal.

The 1S-2S energy difference is to leading order determined by the positron mass, and the antiproton mass only appears as a correction on the level of $\sim 10^{-4}$ via the reduced mass. Measuring the 1S-2S transition therefore primarily constitutes a CPT test in the lepton sector. The ground state hyperfine structure (HFS), on the other hand, is directly proportional to the magnetic moment of the $\bar{\text{p}}$ (that is known only to $\sim$ 0.3 %), and would give a direct CPT test for the antiproton. Furthermore, while the ground-state hyperfine frequency is known experimentally to 12 digits or more, the theoretical accuracy is limited at a level of $\sim 10^{-6}$ because of the non-point like structure of the proton and the poor knowledge of its electric and magnetic form factors. A measurement of HFS for antihydrogen would also test whether the magnetic structures of proton and antiproton are different.

The big challenge in the precision spectroscopy of antihydrogen is the creation of a sufficient number of atoms at rest. The two experiments at the AD are pursuing the scheme where first both charged constituents are trapped in separate Penning traps, then merged and recombined, and finally the neutral atoms should be trapped in a magnetic gradient trap. Altough the recent success of 'cold' antihydrogen production is an important step forward, antihydrogen spectroscopy reaching the precision discussed above is likely to become a project lasting for one or more decades.

2.1.3 Production and usage of very low energy antiprotons

At CERN AD, the ASACUSA collaboration has developed and installed a Radio Frequency Quadrupole Decelerator (RFQD) that can decelerate > 20 % of the $\bar{\mathrm{p}}$ coming from the AD to energies of $20-120$ keV. Such a device dramatically improves the CPT test experiments, by increasing the number of trapped antiprotons for antihydrogen production, or by increasing the number of stopped antiprotons in very dilute gas media (in which the atomic collision effects contributing to the $\bar{\mathrm{p}}$ mass determination errors are much reduced).

In addition, by installing a Penning trap downstream of the RFQD, the antiprotons can be efficiently captured, cooled and extracted as a beam at very low energy (down to 10 eV). During the extraction, the $\bar{\mathrm{p}}$ time structure can be easily controlled. This is being developed by ASACUSA; this ultra-low energy antiproton beam (named MUSASHI for Monoenergetic Ultra-Slow Antiproton Source for High precision Investigations) is a unique "facility" in the world, and will attract many atomic collision physicists, as well as nuclear physicist. This is in part due to the fact that the present CERN AD does not have a slow extraction capability, without which many X-ray spectroscopy and/or coincidence experiments cannot be performed.

2.1.4 Nuclear physics with antiprotons

Nuclear physics experiments as have been performed at LEAR usually require a continuous $\bar{\mathrm{p}}$ beam. Therefore they cannot be performed at present, but will become possible when the slow-beam extraction from the trap is fully developed.

Particularly important is the study of the nuclear periphery using antiprotonic atoms. The LEAR PS209 experiment showed that the difference between neutron and proton radii can be extracted from selected antiprotonic X-ray data. More systematic studies using isotopically separated targets are being planned at AD, and more ambitious experiments to determine neutron and proton momentum distributions at nuclear periphery are also being designed. It would be of great interest to extend the neutron halo measurements also to short-lived radioactive isotopes.

2.2 Muon Physics

In the following, three physics topics with pulsed muon beams are presented. They are a search for lepton flavor violating $\mu^-{-}e^-$ conversion processes, a search for the muon electric dipole moment, and a precision measurement of the muon anomalous $(g-2)$ magnetic moment.

2.2.1 Lepton flavor violation

Lepton flavor violation (LFV) has attracted much interest, from theoretical and experimental, in particle physics, since it has a growing discovery potential to find a important clue of new physics beyond the Standard Model, such as supersymmetric (SUSY) extension to the Standard Model.

In terms of new physics searches, some of the notable features in the LFV studies are that (1) LFV might have a sizable contribution from new physics, which could be observable in future experiments, and that (2) LFV does not have any sizable Standard Model contribution, which could become serious background otherwise, like in K and B decays.

In supersymmetric grand unification (SUSY-GUT) models, finite slepton mixing appears unavoidably through radiative corrections in the renormalization group evolution from the GUT scale to weak energy scale, even if the diagonal slepton mass matrix is assumed at the Plank scale. The predicted branching ratios of the $\mu^- - e^-$ conversion processes range from 10^{-17} to 10^{-15} for the singlet smuon mass of $m_{\tilde{\mu}_R}$ of 100 to 300 GeV. They are larger for a large $\tan\beta$ value. The SO(10) SUSY GUT models give an even larger value of 10^{-15} to 10^{-13} by an enhancement of $(m_\tau^2/m_\mu^2) \sim 100$. Minimum SUSY models with right-handed Majorana neutrinos would also predict large branching ratios through the neutrino mixing observed.

The muon system is one of the best places to search for LFV. The sensitivity to LFV is superb in the muon system. It is mostly because of a large number of muons available for experimental searches today (of about $10^{14} - 10^{15}$/year). And a number of muons available would become more in future if a new highly intense muon source (such as PRISM) is realized.

Among various muon LFV processes, a $\mu^- - e^-$ conversion in a muonic atom is the most promising to improve from a point of view of background rates. To improve a sensitivity, a high intensity muon beam of $10^{11} - 10^{12}\mu$s/sec is required. Further, to reduce beam-related background events, a "pulsed" muon beam with high extinction (between pulses) and no pion contamination in a beam are the most critical. To reduce physics backgrounds (such as from a muon decay in an orbit), good energy resolution of the electron detection is needed. For this, a thin muon-stopping target is necessary since the total resolution is dominated by energy loss in the muon-stopping target. PRISM, which is a new highly intense muon source of narrow energy spread with no pion contamination, is being planned to construct at J-PARC. A narrow energy spread without a loss of the muon intensity, which would allow us to use a thinner muon-stopping target, can be achieved by a novel technique of "phase rotation", which also requires a beam to be pulsed. With PRISM, it would be possible to pursue a search for the $\mu^- - e^-$ conversion process at an ultimate sensitivity of 10^{-18}.

2.2.2 Muon electric dipole moment

The existence of an electric dipole moment (EDM) in a muon violates time reversal and parity symmetries. The prediction for the muon from the Standard Model is well below the sensitivity of our proposed measurement., Therefore, a non-zero measurement of the muon EDM is unmistakable evidence of physics beyond the Standard Model, in particular supersymmetric (SUSY) extension in particular.

A new measurement at J-PARC to study the muon EDM at the $10^{-24}e\cdot$cm level is proposed by using the high intensity muon beam with high polarization available from PRISM-II.[2] The EDM experiment design exploits the strong motional electric field sensed by relativistic particles in a magnetic storage ring of the muons.

The statistics needed for the sensitivity of $10^{-24}e\cdot$cm is given by $NP^2 = 10^{16}$, where N and P are the number of muons and their average polarization respectively. A highly intense muon beam from PRISM-II could only be able to provide the required statistics with negligible beam contamination. The systematic error will be studied by deuterons, for which the required flux is readily available.

2.2.3 Muon $(g-2)$ magnetic moment

The measurement of magnetic moments has been important in advancing our knowledge of sub-atomic physics since for a long time. The muon $(g-2)$ experiment, E821 at the Brookhaven National Laboratory, has published the result of μ^+ of 0.7 ppm, and is analyzing the data of μ^-. They represent a significant improvement over the 7.3 ppm measurement from CERN. Regarding comparison to theoretical predictions, if the e^+e^- evaluation on the hadronic contribution are used, the discrepancy from the standard model prediction is about 3 standard deviations, and using τ analysis alone gives a 1.6 standard deviation discrepancy. Substantial amount of work, both theoretical and experimental, is on-going across the world to refine the hadronic contribution. The significance for an indication of new physics will have to wait for clarification of the correctness of the hadron contribution. However, it would be worth to pursue further a precision measurement of the muon $(g-2)$ moment. At J-PARC, a new experiment to aim the designed goal of an improvement of a factor of 5 to 10 over E821 experiment is proposed. This proposal needs a pulsed proton beam from fast 90 bunch extraction.

2.2.4 The trio

In specific models of extension to the standard model, a trio of measurements of the muon LFV, the muon EDM, and the muon $(g-2)$ would be related one another. For instance, in SUSY models, they correspond, respectively, to an off-diagonal element, an CP-violating imaginary part of the diagonal element, a real part of the diagonal element of the mass matrix of superparticle (slepton). The determination of the slepton mass matrix given by these measurements would give the information of the SUSY breaking mechanism occurring at a very high energy scale, This would be the best opportunity to study at low energy. If the three measurements on with high

[2] PRISM-II is a phase rotator for 500 MeV/c muons, whereas PRISM is for stopped muon experiments.

accuracy can be done at the same location, a study of SUSY breaking would grow interactively at J-PARC.

Chapter 3

Facility Overview

3.1 Introduction

To proceed with the antiproton and muon physics programs listed in the previous section, a pulsed proton beam is definitely needed. The nuclear and particle experimental hall (NP hall) currently planned at the 50-GeV PS will have only a continuous proton beam from slow extraction. It does not have any capability having a pulsed proton beam from fast extraction. The neutrino beam line, which uses a fast-extracted proton beam, can not accommodate other experiments. Therefore, **we would like to strongly request the construction of a dedicated pulsed proton beam facility at J-PARC**. A possible location will be north from the 50-GeV PS ring tunnel close to the planned beam abort dump. Proton pulses in the 50-GeV ring are kicked off outside with respect to the 50-GeV tunnel. It is noted that protons to the neutrino beam line are kicked inside.

A possible layout of the pulsed proton beam line and facilities is presented in Fig.3.1. The current plan of the facility consists of a near facility and a far facility. In the near facility, the production targets for muons/pions and antiprotons, the beam dump, PRISM and PRISM-II are located[1]. At the far facility, the antiproton facility and the muon $g-2$ facility are placed. In the following, the proton beam, the near facility and the far facility are described in the subsequent sections.

3.2 Pulsed Proton Beam

A high energy proton beam is of critical importance to the antiproton physics, since the production cross section is larger for protons of higher energy. A high power proton beam is also critical to the muon physics, since a number of pions/muons produced is proportional to beam power which is given by the product of beam energy and beam current. Therefore, the J-PARC 50-GeV PS, which gives high energy (50

[1]Another letter of intent on the PRISM project is submitted separately, and the details should be referred in that report.

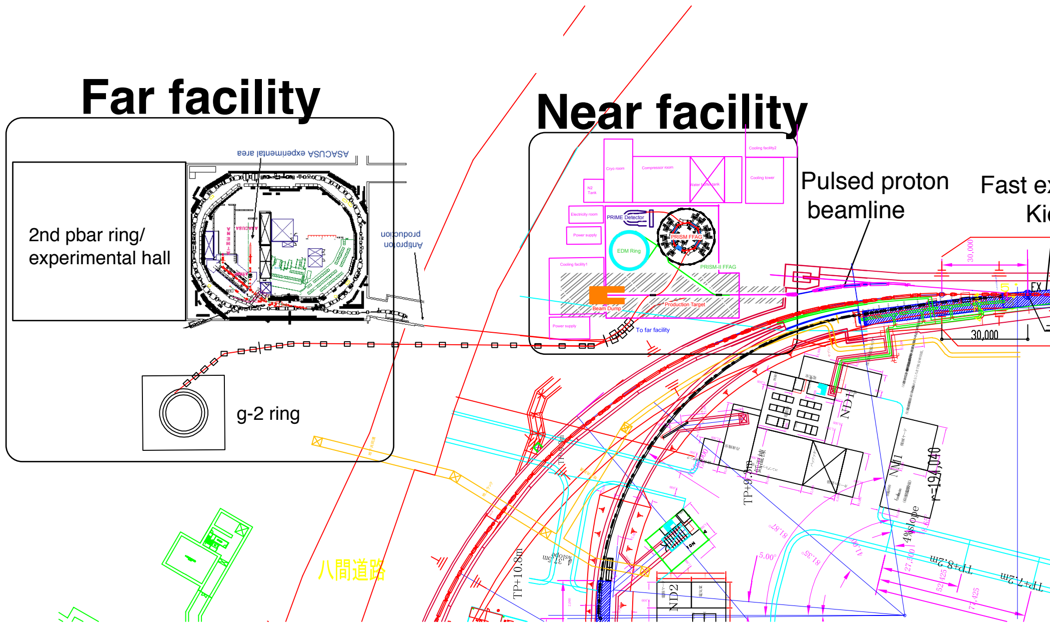

Figure 3.1: A possible layout of the pulsed proton beam facility, consisting of the near and far facilities.

GeV) and high beam power (more than 0.75 MW) , would give a unique and excellent place in the world to carry out these physics programs.

At the 50-GeV proton synchrotron, the beam intensity of 3.3×10^{14} proton per cycle and a cycle time of 0.3 Hz are planned. When operated in a slow extraction mode, the average beam current and a duty factor are 15 μA and 0.20 respectively. The typical cycle structure at the injection to the J-PARC 50-GeV PS is illustrated in Fig.3.2. Four batches (each of which contains 2 bunches) from the 3-GeV proton synchrotron are injected into the 50-GeV PS ring when it stays at a low field. When 8 buckets out of 10 are filled with beams, the 50-GeV ring starts acceleration. The length of every bunch is about 598 nsec (1.67 MHz) and a gap separation is about 300 nsec (*i.e.* 50 % filling). After acceleration to 50 GeV, the pulse width in the J-PARC 50-GeV proton synchrotron is 6 nsec in sigma. It corresponds to a 3 sigma full length of about 36 nsec.

3.2.1 Required time structure

The requirements of the time structure of a pulsed beam for the muon and antiproton physics programs is different. The requirements will be described in the following.

3.2.1.1 Antiprotons

For efficient capture of antiprotons into a ring, the produced antiprotons have to be captured via bunch rotation into a storage ring where they will be cooled via

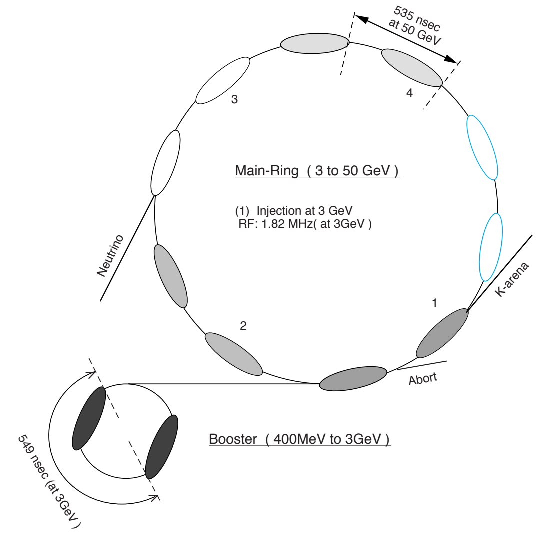

Figure 3.2: Typical machine cycle structure at the injection to the 50-GeV PS

Table 3.1: Main parameters of the 90 harmonics operation.

Parameters	values
Revolution time	5.23 μsec
Revolution frequency	0.191 MHz
RF frequency of 100 harmonics	19.1 MHz
a time period between bunches (central position)	52 nsec

stochastic cooling. The original CERN scheme used one ring for accumulation and cooling, the AA. Later a second ring dedicated for capture was added to increase the production rate. As the magnets and beam pipes of the AA have already been shipped to KEK, it is reasonable to use them for antiproton capture and accumulation as it was done in the early days of the antiproton program at CERN. The AA has a fixed momentum of 3.5 GeV which is optimized for a production beam of 26 GeV. At 50 GeV the optimum momentum is higher, but the higher intensity of the 50-GeV PS would result in a similar production rate at 3.5 GeV as now at CERN.

In the normal operation of the 50 GeV PS there will be 8 bunches in the ring, each 25 ns long and containing 4×10^{13} protons. They are about 500 ns apart, which is too short for stochastic cooling. Likewise, the 90 Hz extraction scheme of PRISM cannot be used for antiproton production, unless a major breakthrough in the stochastic cooling technology can be achieved. Therefore the simplest scheme would be to extract one bunch from the ring for $\bar{\mathrm{p}}$ production. Even in this case, a new target has to be developed to stand the shock wave, but this is true also for PRISM and the neutrino target. To further increase the production rate, a rebunching in the PS would be necessary (e.g., $8 \rightarrow 4 \rightarrow 2$ bunches).

3.2.1.2 Muons

The time structure is critical for PRISM and PRISM-II. They would require a pulsed proton beam of narrow pulse width, since phase rotation needs muons (and therefore their parents, pions, as well) to be within a narrow time spread before phase rotation.[2] If the pulse width of a muon beam is wider, the energy spread achieved after phase rotation becomes larger.

In addition, for muon physics, a high repetition rate, in which a next pulse would come shortly after most of muons in the previous pulse decay out, would be more effective. Note that the muon lifetime is 2.2 μsec. Furthermore, for some types of experiments, an instantaneous intensity has to be lower. Some of the example is a search for the $\mu^- - e^-$ conversion process and the precision measurement of the muon $(g-2)$ magnetic moment. Therefore, many bunches with relatively low beam instantaneous intensity are required. We have studied such a case, and come up with an idea of a 90 bunch scheme.

90-Bunch Operation of the 50-GeV PS

To realize 90 bunches, the proposed scheme is as follows.

1. After proton acceleration, a beam will be de-bunched by shutting RF off. It is the same as in slow beam-extraction.

2. A beam will be re-bunched to 90 bunches by an RF.

3. A bunch will be kicked out one by one (single-kicking mode). Since a bunch separation is about less than 52 nsec, a fast kicker magnet is needed. A repetition frequency of the single bunch depends on the experimental requirements and technical feasibility. In particular, for the search for $\mu^- - e^-$ conversion process and the $(g-2)$ measurement, either 100 Hz or 1000 Hz is being considered.

An expected full pulse width ($\pm$3 sigma) in the 90 bunch scheme is 3.6 nsec (or 0.6 nsec sigma of the width) if a higher RF voltage is used to keep the bucket height the same as in the 10 harmonics operation. The detail parameters are shown in Table 3.1.

There are several issues to be considered. They are listed as follows.

- *Estimation of a time required for de-bunching and re-bunching*: It is guessed to be from 0.1 second to 1.0 second,

[2] The details of phase rotation can be found in the PRISM LOI.

- *Estimation of a possible beam loss in the process of beam de-bunching and re-bunching*: There is a possibility to change a lattice in such a way that the momentum compaction factor from −0.001 to −0.002 so that longitudinal motion is accelerated.
- *Estimation of a pulse width after re-bunching*,
- *Estimation of feasibility on an RF of 90 bunches*, and
- *Estimation of feasibility on a kicker magnet which has 40 nsec of both rise and fall time.*

The main parameters of the RF cavities is summarized in Table 3.2. A total of 5 RF cavities will be used to produce a total of accelerating field of 25000 kV and a total power of 1.25 MW.

Table 3.2: The main parameters of the 90-harmonics RF cavity (one unit).

Parameters	h=90 RF	Nufact-J RF
Frequency	26 MHz	19.1 MHz
Average accelerating field	0.5 MV/m	1.0 MV/m
Cavity Voltage	0.5 MV	1.5 MV
Shunt Impedance	about 1 M ohm	about 1.5 M ohm
Power	250 kW	500 kW

3.2.2 Secondary proton beam line

Proton bunches are kicked off at a similar location where a proton beam to the neutrino beam is kicked. The kicker magnet has been designed to kick protons on both direction, since there is an abort beam line outside the 50-GeV tunnel. Our proton beam line is split from the proton abort line, and is extended to the experimental hall. At the phase of 8 (or 18) bunch running mode, the same kicker magnet is being used. When a beam of 90 harmonics is available, a new fast kicker magnet will be installed near by and is will be used to kick 90 bunches into the line. A design of the optics of the proton beam line from the proton kicker magnet to the PRISM target is under way. A possible layout is shown in Fig.3.3.

3.3 The Near Facility

Fig.3.4 shows a possible layout of the near facility. At the near facility, the production targets (for pions/muons and antiprotons) and a full beam dump will be placed in

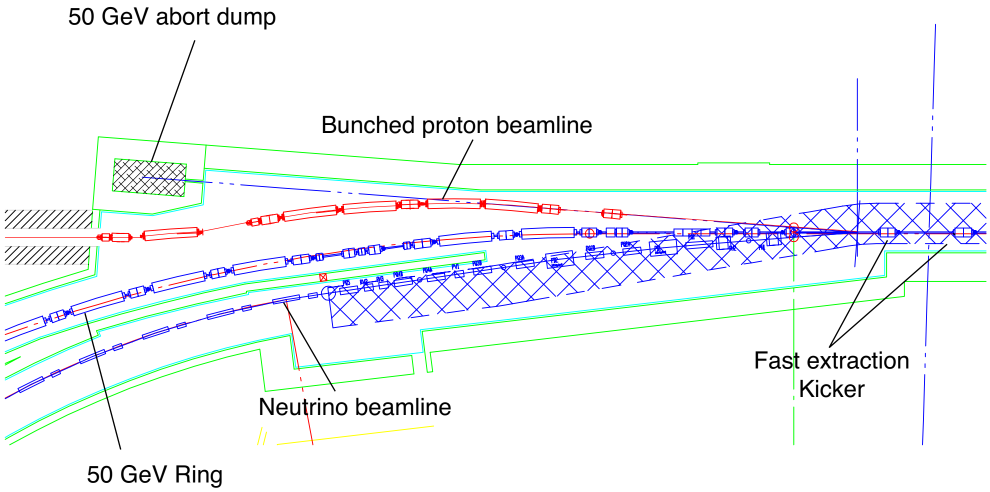

Figure 3.3: A preliminary layout of the pulsed proton beam line.

the primary proton beam line. The experimental floor is composed of two areas, where the one is for PRISM (of low momentum muons with backward extraction) and PRISM-II (of muons of 500 MeV/c with forward extraction), and the other area is experimental apparatus. As a primary particle physics program for PRISM, an experimental search for $\mu^- - e^-$ conversion process (PRIME = PRIsm Mu E) is planned[3]. And, a search for the muon electric dipole moment is planned at PRISM-II. The first target station is used for PRISM-II. The second target station can be used for PRISM and the muon $g-2$ experiment, and antiproton experiments. Multiple targets could be installed at the second target station, but one at a time to optimize for each experiment. The secondary beam line which is indicated as "To Far Facility" goes out from the near facility toward the far facility (through probably underground below the public road). They will be used as antiproton transport as well as pions for the muon $g-2$ measurement. The facility might be either on-ground or underground, depending on handling of the "category-I" wind-break forest.

3.4 The Far Facility

3.4.1 The antiproton facility

3.4.1.1 Antiproton production and cooling

As it does not make sense to just copy the existing AD once more, an antiproton facility of J-PARC should again use accumulation in the AA to increase the production rate, and provide both pulsed and continuous extraction as it was done before at LEAR of CERN. In addition to the AA, a dedicated ring (such as AD) will be

[3] LOIs are submitted separately.

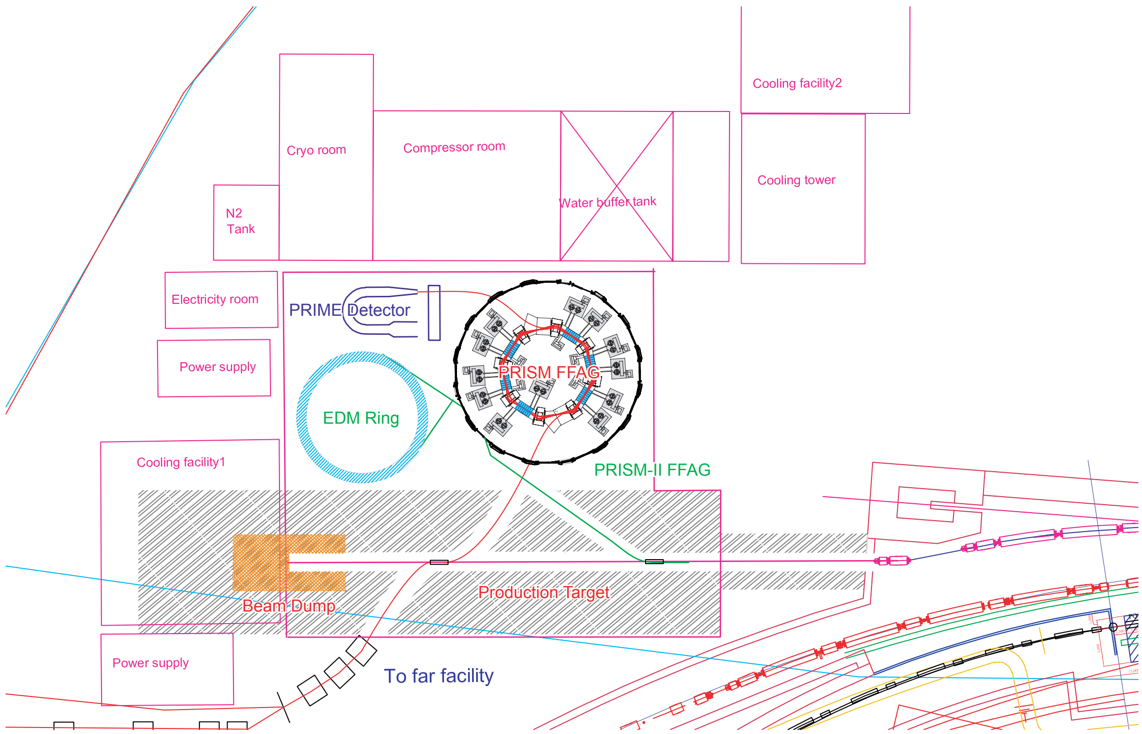

Figure 3.4: A possible layout of the Near Facility where PRISM and PRISM-II are installed.

needed. It was agreed that the AD can also be shipped to Japan if CERN decides to terminate its operation. In addition an experimental hall will be needed to allow for more space and flexibility as at the AD. Here the experiments are located inside the ring, which has already led to very severe space and logistics problems.

3.4.1.2 Location of the antiproton facility and its relation to PRISM

Our study shows that a $\bar{p}$ facility should be located outside the 50-GeV PS, in contrast to the neutrino target that will be installed inside the ring. A fast extraction kicker is already foreseen for a small beam dump, and PRISM has also chosen this location.

The construction of both PRISM and a $\bar{p}$ facility at the fast extraction point requires that both share the same primary beam line and beam dump, in order to avoid large constructions and cost. Due to the different requirements for target size and time structure of the production beam, the target station cannot be shared. The most feasible scheme will foresee two sequential target stations with a common beam dump. Here the $\bar{p}$ facility is located on the opposite site from the public road. An important constraint is that the primary beam should not cross the public road due to radiation safety concerns. The proposed layout foresees the construction of the $\bar{p}$ facility mostly outside the protected forest area, but part of it and also part of the experimental hall will extend into this region.

3.4.2 The muon $g - 2$ ring

The proposed $(g-2)$ experiment needs 90 bunches of a pulsed proton beam to reduce an instantaneous rate. It also needs development of a lithium lens or magnetic horn to further an increase muon intensity. The beamline where pions decay into muons is about 100 m long. The experimental hall has to have a capacity accommodating the 14 n diameter $(g-2)$ ring, together with services. A counting room close to the experimental area would also be needed.

Chapter 4

Future Extension toward A Neutrino Factory

The proposed pulsed proton beam facility could also provide a path toward a future neutrino factory. For instance, the PRISM-II ring in the near facility is almost the same as the first muon acceleration ring. Together with a high beam power target station, the PRISM-II would give the promising first step toward realization of a neutrino factory in Japan (Nufact-J). In this chapter, we present the description of a neutrino factory and the connection of the pulsed proton beam facility and the neutrino factory.

4.1 What is a Neutrino Factory ?

A neutrino factory is a high-intensity neutrino source based on muon storage ring. The neutrino beam energy ranges from a few GeV to several 10 GeV. The beam intensity anticipated at a neutrino factory is about 100 times the present intensity of conventional beams based on pion decays in the corresponding energy region. It is firmly believed that a neutrino factory would open great opportunities for significant progress in neutrino physics. Historically, it was considered based on the R&D works of a $\mu^+\mu^-$ collider. Therefore, all the efforts toward a neutrino factory could have potentials leading the realization of future energy-frontier $\mu^+\mu^-$ colliders at TeV energy range.

In the design of a neutrino factory, muons of 10-50 GeV are injected into a storage ring. Muon decays in the long straight section of the muon storage ring would provide a high intensity beam of neutrinos. A number of neutrinos of about $10^{20} - 10^{21}$ νs/year/straight section is aimed. Both μ^+s and μ^-s are used to produce four different flavors of neutrinos, ν_e, $\overline{\nu}_e$, ν_μ and $\overline{\nu}_\mu$ from $\mu^+ \to e^+ + \overline{\nu}_\mu + \nu_e$ and $\mu^- \to e^- + \nu_\mu + \overline{\nu}_e$ decays. To identify neutrino or anti-neutrino events at the detector, the charge discrimination is required at detection.

A neutrino factory is needed to make precision measurement of neutrino oscillation at a long baseline. The precision of 10^{-3} or better will be needed to determine all of the physics parameters in the lepton sector. To achieve, a high intensity beam of neutrinos with full understanding of beam characteristic is required. To meet all the requirements, a neutrino beam from muon decays must be the best candidate in the following reasons:

1. higher neutrino-beam intensity at high energy, of $10^{20} - 10^{21}$ neutrinos/year, which is about 100 times intensity at a few 10 GeV energy range. In particular, energetic ν_e ($\overline{\nu}_e$) beams can be available at only a neutrino factory,

2. lower background of $10^{-4} - 10^{-3}$ level (which is compared with a few % level at the pion source), and

3. precise knowledge on neutrino intensity and emittance.

Thus, a neutrino factory is suitable for precision measurements. At the neutrino factory, the oscillation signature is determined by a wrong-signed lepton. In practice, the discrimination of e^+ and e^- is more difficult than that of μ^+ and μ^-. And therefore, $\nu_e \rightarrow \nu_\mu$ ($\overline{\nu}_e \rightarrow \overline{\nu}_\mu$) are looked at at a neutrino factory.

4.2 Japanese Scenario of a Neutrino Factory

The Japanese scenario of a neutrino factory is based on the scheme of FFAG (Fixed-Field Alternating Synchrotron) acceleration. In this scheme, after the muon capture, a series of FFAG rings are used to accelerate muons of large emittance. It is only possible since FFAG is the only machine which has a large acceptance. A possible layout is shown in Fig.4.1. In the layout, there are four rings, where the first ring is acceleration from 0.3 GeV/c to 1 GeV/c, the second is from 1 to 3 GeV/c, the third is for from 3 to 10 GeV/c, and the forth is from 10 to 20 GeV/c. Note that the design of the first 0.3-1 GeV/c ring is almost the same as the PRISM-II ring. Therefore, PRISM-II would serve as the first acceleration ring. The second, third and forth rings should be located deep underground. For this scheme, the total accelerator complex could be simple and compact.

A staging approach should be seriously considered to construct a large scaled project like a neutrino factory. This staging approach is demanded in two folds. One is to maintain a total budget profile to be a reasonable size at different stages to get the funding easier. The second is that establishing required technology will require a long term, whereas we like to keep physics activities even in the R&D period. In our FFAG acceleration scheme, it is possible since we start with the first acceleration ring, and add downstream FFAG rings at a later time. Possible connection to physics programs is listed in Table 4.1.

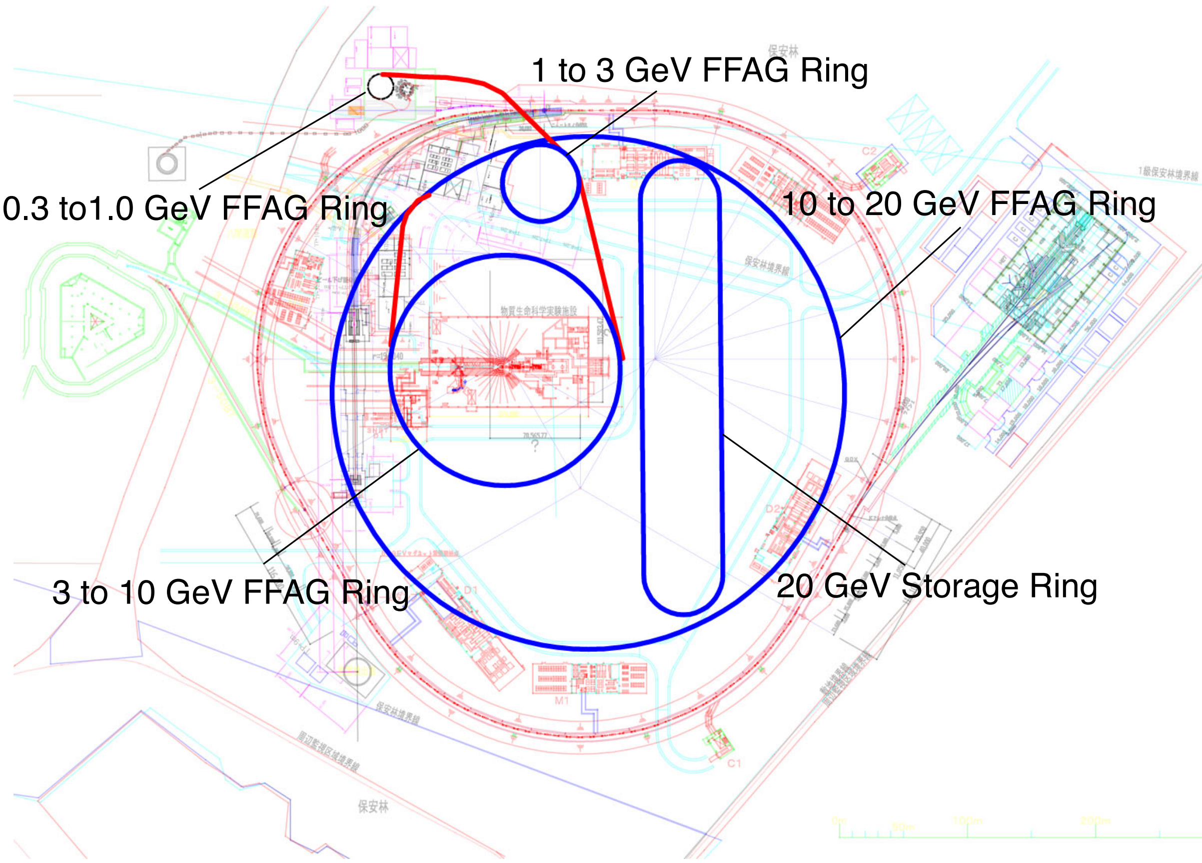

Figure 4.1: A possible layout of the FFAG-based neutrino factory.

Table 4.1: Possible scenario of the staging based on FFAG acceleration.

Stage	FFAG ring	Potential Physics Programs
0	Low energy ring (PRISM)	muon LFV
1	0.3-1 ring (PRISM-II)	muon EDM and low-energy neutrino source
2	1-3 ring	1 GeV neutrino source
3	3-10 ring	an initial neutrino factory
4	10-20 ring	a full size neutrino factory

Chapter 5

Request at Phase-I

The construction of the pulsed proton beam facility is not included in the Phase-I plan of J-PARC according to the J-PARC schedule. However, it is important to keep its possibility at the phase-I construction. One concern is activation of soils around the area of the fast extraction port from the 50-GeV protons in the ring. If soils at that area are activated, future excavation of the tunnel for a proton beam line would become severely difficult. To avoid activation, we like to place some concrete shielding blocks at the location of proton extraction. Possible arrangement which we are considering is shown in Fig.5.1.

The thickness of the shielding blocks required was calculated based on the Moyer formula which assumes a linear radiation loss. From the calculation, with a concrete shielding of 2.2 meter thick in addition to the 0.8 meter thick of the 50-GeV tunnel wall, soil activation would be about 0.07 msv/h and 0.02 Bq/g. It is much less than the acceptable level of 0.3 msv/h and 0.1 Bq/g. From this, it is shown that with this amount of the concrete shielding blocks it would be possible to excavate at a later time.

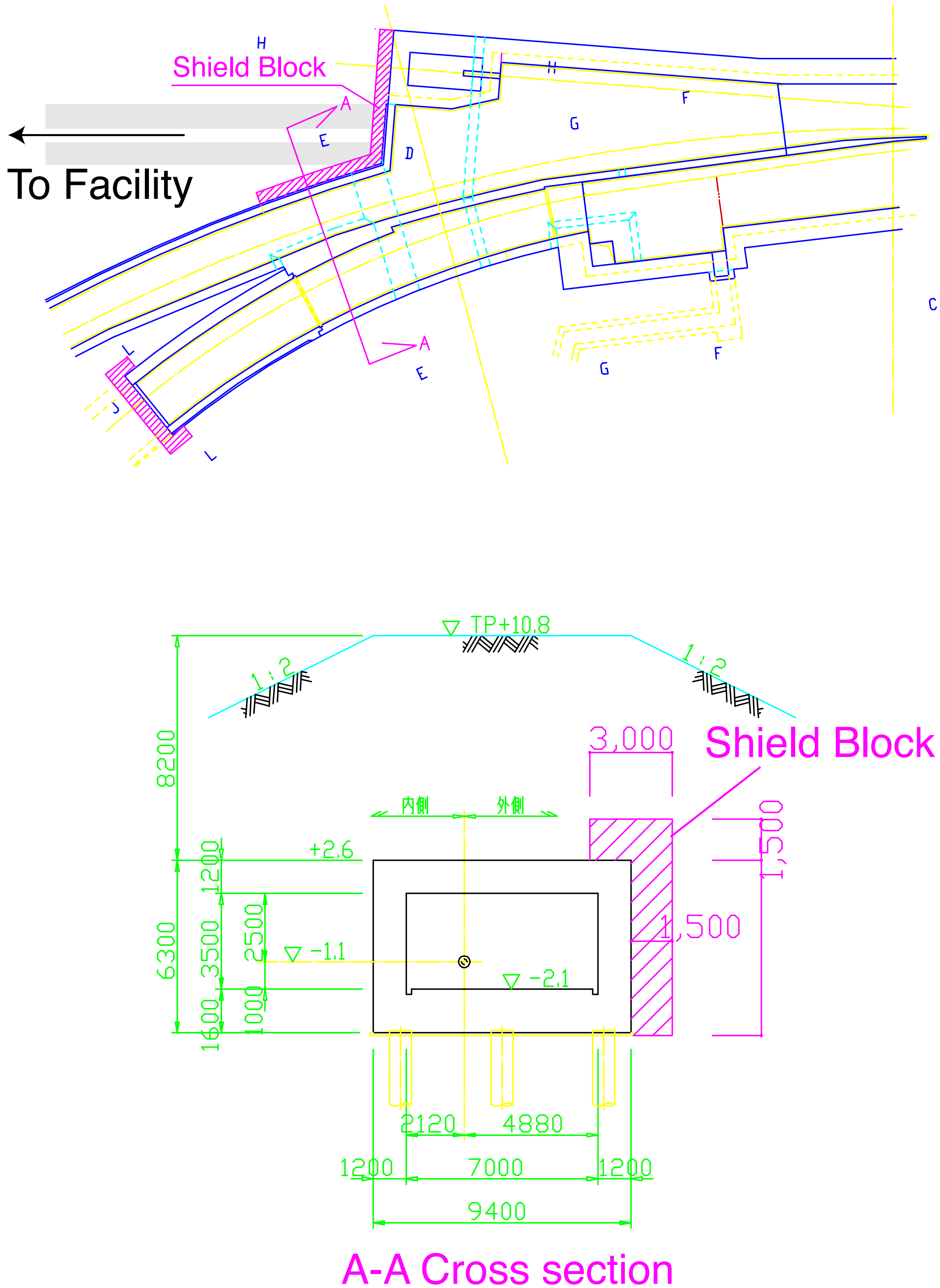

Figure 5.1: Possible arrangement to avoid soil activation around the location of proton extraction.

Chapter 6

Conclusion

We have shown potential physics programs with antiprotons and pulsed muons, which could be achieved if a pulsed proton beam facility is built at J-PARC. Those physics programs have a large discovery potential to new physics beyond the Standard Model. Although a pulsed proton beam facility is not included in the Phase I plan of J-PARC, we would strongly request the construction as the earliest as possible.

At Phase I, we would like to request special arrangement to avoid soil activation at the location of the future proton extraction port.