Beamline Layout Plan of the Hadron Experimental Hall

－ Report to the 3rd NPFC meeting －

Nuclear and Particle Physics Facility Construction Group

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1. Introduction

The review of letters of intent (LoI) at the June 2003 meeting of the Nuclear and Particle Physics Facility Committee (NPFC) was the first step to establish a policy for designing a beamline layout at the J-PARC 50 GeV hadron experimental hall. The NPFC provided to the project director its assessment of the physics impact, comments on technical aspects, and recommended experimental schedule for each LoI. The NPFC classified a few as Day-1 experiments, 16 as Phase-1 type, and some others as Phase 2 or later projects. Subsequently in September, the project director instructed the project construction team to prepare a facility design and construction scheme for the hadron experimental hall in addition to other instructions concerning the neutrino facility construction and future projects.

The construction team formed a working group[1] to make a detailed plan. The group held 5 working sessions since Fall 2003. The present report is a summary of its recommendations. Strictly speaking, the group is providing a list of possible options from which the PAC may make choices in near future. This report is organized as follows: Section 2 lists the beam requirements of the LoIs and the NPFC's recommendations. Section 3 summarizes the instructions of project director to the construction team. The original document is in Japanese. It also lists the constraints (financial and technical) that the group has to contend with. The latest set of parameters of Phase-1 facility is given in section 4. Section 5 describes the general layout of the Phase-1 facility. Some possible options for the beamline parameters and arrangements are described in section 6. The current schedule for the construction is detailed in section 7. The future extensions to Phase-2 are briefly addressed in section 8.

[1] The members of the working group were; J. Imazato, T. Inagaki, T. Komatsubara, H. Noumi, T. Sato, S. Sawada, and K.-H. Tanaka.

2. Hadron experimental hall in Phase 1

The design of the Phase -1 experimental hall is well advanced. The main features such as hall dimensions, switch yard length, electrical and water services, are fixed. Some minor changes are still possible, though at some extra design cost. The table below lists the parameters of the Phase 1 experimental hall.

[Building]

- Switchyard length 180 m
- Elevation from the ring 2.9 m
- Hall width (in m.w.d.) 58 m
- Hall length (in m.w.d.) 56 m
- Hall floor level -6.4 m from the ground level

[Primary beam]

- Primary line A1 line (straight line)
- Beam energy 30 GeV in Phase 1
- Production target T1 target
- Beam height 2.0 m above floor
- Location of the line In the middle of 58 m width

[Services]

- Electricity capacity for 1 secondary line and 1spectrometer in addition to 30 GeV primary operation
- Cooling water capacity for 1 secondary line and 1 spectrometer in addition to 30 GeV primary operation

3. Beams requested by Letters of Intent

The NPFC reviewed 30 LoIs including the neutrino oscillation experiment and future facilities. Their requested beams are listed in the attached table (Table of Letters of Intent and Requested Beams). Regarding the hadron beam experiments the NPFC evaluation classified them as Day-1, Phase 1 and Phase 2+ experiments *etc*. The Day-1 and Phase 1 experiments are relevant for this report. They may be grouped into 6 categories as per their beamline needs. These beamlines are nominally;

- K1.8 and K1.1 for nuclear physics and relevant to Day-1 experiments (L-06 and L-10) and other experiments (L-01, L-07, L-08, L-09 and L-21),

- KL for neutral kaon rare decay experiments (L05),
- K0.8 for charged kaon decay experiments using stopped beams (L-04, L16, L-19, and L-20),
- High-momentum lines for hadron physics (L-11, L-14, L-13, L-15, L-18 and L-23), and
- Test beamlines (L-02).

4. Philosophy of the beamline layout

The philosophy of the beamline layout was guided by a) the director's instructions to the team and b) technical and financial constraints. They are detailed below.

4.1 Director's policy

We were given the following instructions from the director concerning the hadron hall layout.

1) At first, make all attempts to construct the K1.8 and K1.1 beamlines requested by the two Day-1 experiments, L-06 and L-10. If it proves impossible to build both lines simultaneously, make plans e.g. to install the K1.8 with a provision to accommodate the K1.1 at a later date.

2) Even though there are no budgetary measures at the moment, consider the installation of test beamlines positively.

3) Design the experimental hall so as to accommodate the three kaon decay experiments (L-05, L-04 and L-19) in the future.

4) Don't shut the doors on the experiments which received a lower evaluation. It may be that they would develop to become good experimental proposals in course of time.

5) Make a detailed beamline layout for Day 1 and a facility construction plan for phase 1 taking the above criteria into consideration.

4.2 Technical and financial constraints

a) Cost-effectiveness and shielding efficiency dictate that the radiation shielding walls of the primary A line and part of the switchyard exit be built of cast concrete. Once built, it will be impossible to change the rigid wall structure. Thus, it is essential that the necessary secondary beamlines of Phase 1 are considered in great detail before the wall structures are determined.

b) It will be very difficult to modify the production target or upstream parts of secondary beamlines after a period of full-intensity operation. The secondary beamlines should try to make use of the structures of the upstream beamlines. It is desirable that components of all planned beamlines are installed along with Day-1 parts.

c) The high momentum beamline, which was identified as the primary C-line in the original design and requested by several LoIs is not included in the Phase 1 budget. Also, neither the A-line nor the exraction line is usable for a primary beam experiment. Thus, the beam preparations for those experiments will require additional efforts at a later date, possibly after the start of Phase-1.

d) There is no money allocated for secondary beams in J-PARC budget except, maybe, for minor installation costs. The construction team is striving hard to complete at least one secondary beamline to abide by the NPFC recommendation and the Director's guideline. A budget deficit is already foreseen and monies have to be found from somewhere. If no funding is forthcoming, the recommendations and guidelines have to be modified accordingly

5. Phase-1 layout

Figure 1 shows the general layout of the experimental hall. The concrete shielding structure is shown in detail. The K1.8 line, a requirement for the LoI-06 Day-1 experiment is in place. It is located at 6 degrees to the left of the primary beam line starting off at the target T1. There is room for another charged particle beam line to the right side of the primary beamline also at 6 degrees. This line may be designated as K1.1 and/or K0.8, either in a single or branching scheme with two stages of electrostatic separation. There will be two possibilities of S-type and C-type options. The KL line can be also accommodated in the right-hand side with the take-off angle of 16 degrees. There will be no conflict with regards to experimental area between K1.1/K0.8 and KL in the current proposed size of the experiments. There will be a branch of K1.8 (K1.8-BR) possible after the first stage of electrostatic separation (DCS). A possible direction of a high-momentum line is indicated. This line crosses the K1.1/K0.8 S-type area but might be compatible with the C-type option (see Fig.1) of K1.1/K0.8 if beam-crossing (at a different height) scheme is considered. A few options for the test beams are suggested below.

Table 1 Beamlines to be able to prepare in Phase 1

Beam line	Target	Angle	Relation to other lines
K1.8	T1	-6 degrees	no conflicts
K1.1	T1	+6 degrees	coexistence with K0.8
K0.8	T1	+6 degrees	coexistence with K1.1
KL	T1	+16 degrees	no conflicts
K1.8-BR	T1	-6 degrees	branch of K1.8
High-*p*	SM1	-	conflict with S-type K1.1/0.8
Test beam	T1		several options using the above channels

6. Possible beamline structure and parameters

6.1 K1.8 for Day-1 experiments

The optics of the intermediate momentum line K1.8 is very well worked out. The line fits along the hall length and there is room for the experimental area to accommodate the SKS spectrometer. The beam channel has a double stage separator and it delivers nearly pure kaon and pion beams of momenta < 2 GeV/*c*. The present design parameters are summarized in table 2. It is good to note that they meet the requirements of the LoIs, especially those of the Day-1 experiment. The hadron beam subgroup of the construction team is developing the concept of secondary beam lines at a high-intensity machine. The upstream part of the channel needs special consideration in view of the possible excessive beam heating of the beamline elements such as collimators, magnets and beam windows. The R&D of these components is in progress. A scheme with a few front-end magnets in a vacuum vessel will be adopted. In the consequence it seems that the intermediate focus optics is the most promising option for this line. It will also be possible to extract a high resolution branch beam, albeit it will be of a single separator.

Table 2 Main parameters of K1.8

Length	45.7 m
Maximum momentum	2.0 GeV/*c*
Acceptance	2.9 msr % @MS1=±2mm, MS2=±2mm
K- Intensity	13×10^{6} /spill @ 1.8 GeV/*c*, 50GeV, 15μA*p*
	3.1×10^{6}/spill@ 1.8 GeV/*c*, 30GeV, 9μA*p*
Separation	double stage
K^{-}/π^{-}	>> 1
Momentum resolution	0.03% in σ

6.2 K1.1 for Day-1 experiment

The lower momentum beam K1.1 will be installed on the other side of K1.8. The conflict with the KL line and its experimental area could be avoided by tuning the extraction direction. This channel will be equipped with two DC systems, too. The final focus is achromatic. The fine tuning of optics is now underway, and current design parameters are listed in Table 3. The upstream parts of the channel will be almost symmetric with the K1.8 and put in the vacuum tank. The intermediate focus scheme will be adopted, too. As mentioned below it will be also possible to install a branch in order to realize the low momentum line K0.8.

The K1.1 area might conflict to high-momentum beam experiments in the later period of Phase 1 when the high-momentum line will be mounted. This conflict may be resolved if a C-type channel structure (see Fig.1) will be adopted in stead of the current S-type basic optics design.

Table 3 Main parameters of K1.1(S-type)

Length	25.8 m
Maximum momentum	1.1 GeV/*c*
Acceptance	4.4 msr % @MS1=±1mm, MS2=±1mm
K- Intensity	12×10^{6} /spill @ 1.1 GeV/*c*, 50GeV, 15μA*p*
	2.9×10^{6}/spill@ 1.1 GeV/*c*, 30GeV, 9μA*p*
Separation	double stage
K^{-}/π^{-}	1.7

6.3 Beamlines for other Phase-1 experiments : KL

The KL beam request for Phase 1 is the beam off T1 target with a take-off angle of 16 degrees. Although the KL beam intensity is not the optimum for the experiment, the group is requesting step by step sensitivity improvement with this option as the first phase. They also keeps an option using a high intensity primary line other than A. The working group investigated the feasibility of the right-hand side extraction together with the charged line K1.1/K0.8 (Fig.2). It was confirmed that the layout is possible by designing the T1 downstream collimator so as to extract the 16 degree beam. It is necessary to make transmission holes in the yokes of the first K1.1/K0.8 magnets. The T1 downstream vacuum chamber should be designed accordingly. Although the first KL collimator will be 6 m away from the target, the KL yield will be sufficiently high. The existing K0 line from the 12 GeV PS with minor modifications may be transferred to J-PARC. We anticipate no serious problem with the alignment although some arrangement will be necessary for the front-end collimators before the start of operation. The experimental area will be large enough to accommodate the E391a scheme.

Table 3 Parameters of the KL line of the A-T1 option

Length of the channel	20m
Distance to collimator	6m
Acceptance	4.5×10^{-6} str
KL intensity / 10^{14} proton	1.7×10^{7}
Neutron/K_L ratio	4

6.4 Beamlines for other Phase1 experiments : K0.8

The K0.8 line is mainly for stopped K^+experiments and requested beam momentum ranges from 0.6 to 0.8MeV/c spreading due to slightly different experimental conditions. We evaluated the feasibility that the proposed K1.1 be used for this purpose. This is not an optimum choice for experiments requiring maximum intensity. A shorter line should be pursued. The upstream part of the channel will be not different from that of K1.1 for the reasons mentioned in section 4.2. The requests for low π to K ratio requires necessarily double stage separation which renders it difficult to shorten the channel length. In the relation to K1.1 the following options conceivable.

1) Use of K1.1 which is optimally designed for strangeness nuclear physics with lowered momentum. No additional cost is incurred for the beamline construction. This option has, however, disadvantage of low kaon beam intensity and also only one setup can be done. The beamline and experimental area will have to be shared with nuclear physics experiments.

2) Design of an optimal low momentum double stage line in place of K1.1. The kaon beam intensity can be optimized, but we will have the same problem as in 1).

3) Branch the K1.1 line at the intermediate bending magnet and form a C-shape achromatic line (see Fig.1) with more or less optimal design for stopped kaons with double stage separation. The upstream part of K1.1 is subject to modification from the single K1.1 line to optimize both downstream branches. Although the beamline operation will be time-shared (probably by replacing the intermediate magnet), this option will be attractive since

- Two experimental areas allow two setups simultaneously, and
- We can accommodate this line along with a high-momentum beam line. (As mentioned before, there is also a possibility that the K1.1 line and its area take this choice at the installation of a high-momentum line.)

6.5 High-*p* line for Phase-1 hadron physics experiments

The proposed high-momentum line is a line starting from the SM1 point at the upstream of the proton extraction line. The primary proton "C" line in the original plan corresponds to this line. For primary proton beams, devices such as a beam stealer can be used to separate a portion of primary proton beams at SM1. For high momentum secondary beams, a thin (up to 2% loss) target can be used at SM1. The intensity of the secondary beams achieved will be: the order of 10^7 /sec for pions, the order of 10^4 to 10^6 for kaons, and the order of 10^4 to 10^6 for antiprotons. The working group examined the feasibility to layout high-momentum beam experiments in the hall. The proposed experimental apparatus will not interfere with the KL apparatus. If the K1.1/K0.8 beam is constructed as an S-type, experimental apparatus will interfere with each other. If the K1.1/K0.8 line is a C-type, both crossing lines as well as the experimental areas can be accommodated as shown in Fig.3. However, note that the installation of high-momentum line (or second primary line) is not included in the Phase-1 budget. Thus, some efforts (e.g. efficient use of operation money *etc*.) are needed to realize this beamline.

6.6 Beams for test experiments

In the original design of the facility plans were made for a test experimental hall beside the switchyard and also to extract two test-experiment beams from a thin target T0. But this hall was dropped in Phase 1. Now the only possibility is to use the T1 target. Considering that T1 is crowded with beamlines and also for budget reasons permanent line of high performance may not be realized. The solution would then be to prepare a beam which satisfy the minimum requirements of the test beam LoI by coordinating the possibilities around T1. Thus, the beam availabilities will depend on other experimental program and time. In the following several options are suggested.

1) Use of the K1.8 branch line as a parasite or time-sharing user. If the construction of K1.8 has a high priority, this option will be very realistic. One installs a short branch leg after the first DCS stage. A fairly large space for a setup is available. The beam momentum will be up to 2 GeV/*c*. The sort of beam will depend on the operation of the K1.8 main user when parasitic. There will be no problem with the intensity.

2) Use of K1.1/K0.8 or KL holes before the start of main experiments. In the initial stages of Phase 1, it is not conceivable that all the secondary lines will be fully equipped and experiments are setup. Actually we are going to make a realistic plan of beamline installation. In such a case a simple low-cost test line can be put in the extraction holes. At the KL hole one may extract a higher momentum beam.

3) A pinhole beam extraction from T1. For the use of very low beam rate a straight pinhole (with a diameter of several to ten cm) will be prepared to look at T1. The extraction angle will be about 45 degrees and emerge at the K1.8 branch area. A simple magnet system will be adequate to prepare an analyzed beam. The diameter of the hole will be optimized to fulfill the LoI minimal requirement of intensity and energy. We may expect 230 π^-/s of 2 GeV/*c* for 3cm diameter hole at the 30 GeV-9μA proton beam. This hole can be used also for the purpose of target monitoring.

In the later period of Phase 1 there might be a chance to install a high-momentum line (or primary C-line) from an upstream SM target. Then, a branch can serve as a high momentum test line. The early realization of the test hall should be pursued, too.

7. Construction schedule and budget constraints

It is now planned to complete the building construction by the end of Japanese fiscal year 2006 and the installation of the primary beamline 2007. The experimental facility including secondary lines will be completed sometime in 2008. Although the first proton beam will be delivered in JFY 2007 in the last year J-PARC budget, the start of experimental secondary beam will be scheduled in 2008.

The construction group is supposing to setup the two lines of K1.8 and K1.1 as high priority lines at the moment, following the LoI evaluation by the NPFC and director's guidelines. However, the current cash flow allows, at most, only the completion of one secondary line. Even this relies heavily on the injection of large amounts of funds from sources other than J-PARC budget. It is estimated to amount to more than 50% of the J-PARC hadron facility equipment budget. If this plan is realized, the project team intends to build the K1.8 line, for which the beam optics has already been worked out and the design of beam channel has begun. If the extra money is not found, one needs to revisit the priority scenario. The present plan of the floor layout allows any of the K1.8, K1.1, KL and K0.8 as the Day-1 option. The project team think that the final decision on the first beam should be made by the PAC based on the final approval of the Day-1 experiment in not too distant future. The beamline priority scenario is also a problem coupled to the preparation and readiness of experiments for Day-1.

8. Plan for Phase 2 extension

The construction group will constantly be seeking to get Phase 2 approved . Once it is approved and the extension of the hall to 100 m length happens, the beamline layout plan will be reconsidered. The extension cannot be too late because the beam dump will be rolled downstream and if it is too strongly activated, the work will become very difficult.

Even if the hall extension does not happen soon the increase of service capacities should be realized as soon as possible to enable us to run two secondary lines at least simultaneously. The increase of the proton beam energy to 50 GeV will depend on demand from experiments, but will be of less importance before the hall extension.