Letter of Intent
for
Construction of a High Momentum Beam Line at the 50-GeV Proton Synchrotron

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J. C. Peng[1], S. Sawada[2†], T. -A. Shibata[3], H. Spinka[4], K. H. Tanaka[2], and S. Yokkaichi[5]

[1] *Department of Physics, University of Illinois at Urbana-Champaign, Urbana, IL 61801-3080, USA*
[2] *High Energy Accelerator Research Organization, Ibaraki 305-0801, Japan*
[3] *Department of Physics, Tokyo Institute of Technology, Tokyo 152-8551, Japan*
[4] *Physics Division, Argonne National Laboratory, Argonne, IL 60439-4843, USA*
[5] *RIKEN (Institute of Physical and Chemical Research), Saitama 351-0198, Japan*

Abstract

We propose construction of a multipurpose high-momentum beam line originated from the SM1 separation point, where beam loss of 15 kW is allowed from radiation protection point of view. This beam line can be used for various experiments which use secondary beams (pions, antiprotons etc.) and primary beams (protons, heavy ions and polarized protons) of the momenta larger than 4 GeV/c. About 10^9 per second primary beams and several $\times 10^6$ per second pion beams can be delivered from the beginning of the operation of the 50-GeV synchrotron.

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†Contact person: S. Sawada (shinya.sawada@kek.jp).

1 Introduction

In the phase 1, the experimental hall of the nuclear and particle physics facility at the 50-GeV Proton Synchrotron is about 60 m wide and about 56 m long, with future possibility to be extended downstream. With this short experimental hall, no beam line with its highest momentum greater than about 4 GeV/c can be constructed. For example, even if the T1 target (30% loss target in the A line) is constructed, the maximum momentum of a beam line from T1 will be about 4 GeV/c. In order to utilize the performance of the 50-GeV synchrotron, it is indispensable to use not only low momentum beams but also high momentum beams. In addition, possibility of using not only secondary beams, such as pions and anti-protons, but also primary beams, such as protons, polarized proton and heavy ions, is highly desirable.

On the other hand, a rather long ($\sim$ 150 m) switching yard allows handling of higher momentum beams. Three positions inside the switching yard allow beam loss up to 2% (15 kW), where production targets or beam separation equipments can be placed. A high momentum beam line originated from one of these positions can be constructed through the switching yard.

Similar facilities in the world certainly have beam lines which can handle high momentum beams up to their primary beam momentum. For example, the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory has several high momentum beam lines up to 28 GeV/c, such as A1, A3, B1, C1 and C5. The CERN Proton Synchrotron has high momentum beam lines (T7, T8, T9 and T10) in the East Area up to 24 GeV/c. Since the 50-GeV synchrotron should be the world-leading facility in nuclear and particle science, it should have such a high momentum beam line from the beginning of its operation.

This Letter of Intent intends to propose construction of a high-momentum beam line at the 50-GeV experimental hall. In Sec. 2, needs from physics proposals are summarized. In Sec. 3, details of the beam line is presented, followed by a summary in Sec. 4.

2 Physics

Many experimental groups have plans of studies using high momentum beams from the 50-GeV synchrotron. Table 1 shows examples of the experiments which needs high momentum beams.

While details of these studies are described in their separate Letters of Intent, their requests on high momentum beams can be summarized as follows:

- primary proton beam, $\sim 10^{12}$ / $\sim 10^{9}$ pps
- primary heavy ion beam, $\sim 10^{10}$ pps
- primary polarized proton beam, $\sim 10^{12}$ pps
- secondary beam, $\sim 10^{9}$ / $\sim 10^{6}$ pps

The momentum of the primary beams is 51 GeV/c for protons, and 25 GeV/c/A for heavy ions. The momentum range of the secondary beams is from a few GeV/c to about 10 GeV/c. This Letter of Intent proposes construction of a multi-purpose high-momentum beam-line, which provides primary and secondary beams of medium and high momenta up to 51 GeV/c. Please note that a beam line for short-lived particles such as kaons should be considered separately from this proposed beam line.

3 Beam line

3.1 Overview

Because the size of the experimental hall is limited in the phase 1, a beam line with a beam momentum greater than about 4 GeV/c cannot be constructed with the T1 target, which is the planned 30% loss target inside the experimental hall. The alternative is to use SM1, which can tolerate with 2% beam loss of the primary 50-GeV beam with 10^{14} pps, as the origin of the beam line. By placing a production target, a beam stealer (halo collector), an electrostatic septum, or a conventional bending magnet at SM1, this beam line can deliver secondary beams, such as pions and anti-protons, and primary beams of beam momenta from several GeV/c up to 50 GeV/c.

Table 1: Examples of the physics experiments which needs high momentum beams. (pps = particles per second)

Beam Species	Beam Momenta (GeV/c)	Beam Intensity (pps)	Remarks
Dimuon (Drell-Yan and Quarkonia)			
proton	51	10^{12}	
heavy ion	10-25 /A		
Vector Meson in Nuclear Matter			
proton	10-51	$10^9 - 10^{10}$	
heavy ion	10-25 /A		
Hadron Spectroscopy			
π	< 6		
separated K	< 6		
antiproton	2-3	$10^6 - 10^9$	for pol. pbar
pol. proton	30-51		
Spectroscopy of strange/hidden strangeness states			
K	6-10	3×10^6	RF separated
Multifragmentation			
proton	31	several $\times 10^9$	
proton	variable, 4-14	several $\times 10^7$	
π	variable, 4-14	several $\times 10^6$	
heavy ion	10-25 /A		
High p_t Elastic p-p			
proton	30-51	$1 - 4 \times 10^{11}$	SPIN@J-PARC
pol. proton	30-51		SPIN@J-PARC
High Baryon Density Matter			
heavy ion	~ 25 /A		

The design intensity of the primary proton beam from the 50-GeV accelerator is 10^{14} particles per second (pps), and thus consideration on the heat deposit and radiation production should be highly taken into account to the design of the beam line equipments. We think that a thin production target, a beam stealer and a conventional magnet can be constructed with the present technological knowledge, while some R&D works should be necessary to realize a septum which has to be used to generate a beam of a few % of the primary beam. In addition, beam loss around the target section has to be carefully taken care of from the viewpoints of heat and radiation deposition, in order to deliver high intensity ($\sim 10^9$) secondary beams.

With these considerations, construction schedule is proposed to be divided into two stages. The first stage should begin from the completion of the construction of the experimental hall (year 2007), where $10^6 - 10^8$ secondary beams and 10^9 primary beams (10 to 100 ppm of the beam from the 50-GeV accelerator) will be delivered. In a few years for R&D works, the second stage can be realized where 10^9 secondary beams and 10^{12} primary beams (1% of the beam from the 50-GeV accelerator) will be delivered.

Figure 1 shows a schematic view of the beam line. The multi-purpose high-momentum beam line will be constructed as the C line which originates from SM1, while the A line is the major primary beam line which has the T0 target point (for test beam lines) and the T1 target point. The beam line can be extended when the experimental hall is enlarged in the phase 2 of the J-PARC project. An RF-separated beam line, as proposed by another Letter of Intent, may be constructed with the same SM1 target system.

In the following sections, details on the beam line equipments and yield estimation are described.

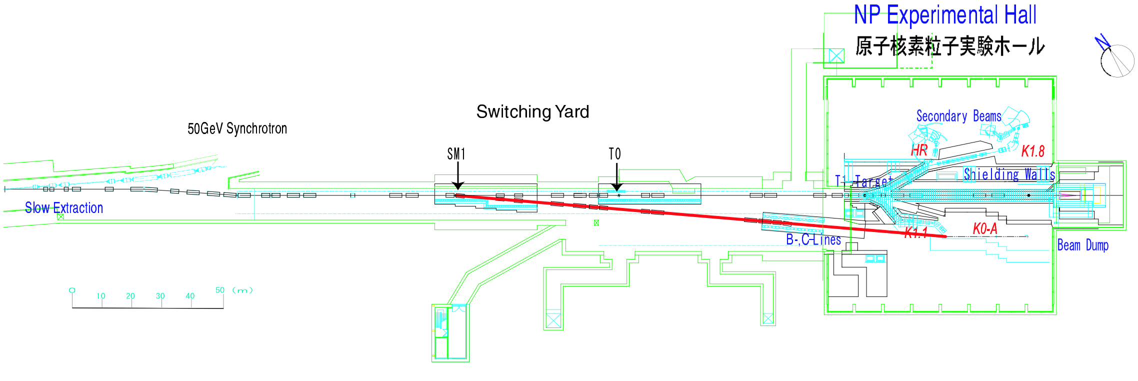

Figure 1: Multipurpose High-Momentum Beam Line (red line).

3.2 Equipments at the switching point SM1

3.2.1 Equipment to slice 10-100 ppm of the primary beam: beam stealer/halo collector

A beam stealer or halo collector will be used to cut out a portion (10 to 100 ppm) of the primary beam. As shown in Fig. 2, a major part of the primary beam goes through the wider opening of a dipole magnet, feels a magnet field and then is bended slightly. The smaller opening does not have a magnetic field and a portion of the beam halo can go through without the magnet field. The magnetic rigidity should be about 3 $T \cdot m$ in order to bend the 50-GeV/c beam with an angle of 1 degree. The beam stealer can be replaced by a conventional bending magnets for weaker primary beams such as a polarized proton beam and heavy ion beams.

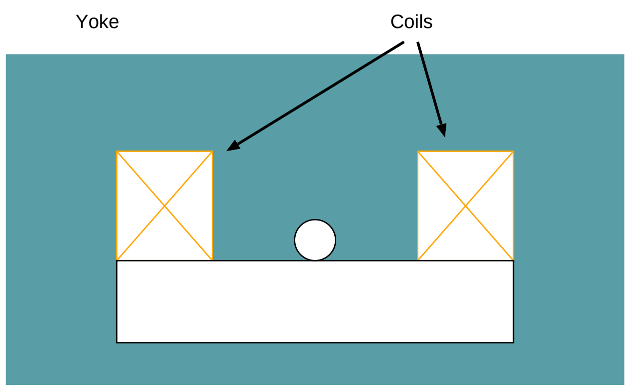

Figure 2: Beam Stealer. The 10 to 100 ppm portion of the primary beam goes through the non-field region of the magnet (shown by a circle).

3.2.2 Equipment to produce secondary beams: production target

In order to produce secondary beams, such as pions, kaons and anti-protons, a conventional metal target can be used. Because the amount of the beam loss at the SM1 has to be 2% or less of the full primary beam (0.75MW) from a radiation protection point of view, the thickness of the target should be 3 mm for copper. The heat deposition has to be removed by cooling water near the production target. This kind of techniques has been realized in the world's fixed target facilities, such as BNL-AGS.

3.2.3 Equipment to bend primary beams: conventional magnet

In order to guide full primary beams to the multipurpose high-intensity beam line (C line), a conventional bending magnet is used. When the intensity of the primary beam from the 50-GeV accelerator is low, for example, in the case of the heavy ion beams or the polarized proton beams, this beam line can tolerate the intensity of $\sim 10^{12}$ pps from the radiation protection point of view. The bending power of the magnet should be 6 $T \cdot m$ in the case the beam is bended with an angle of 2 degree.

3.2.4 Equipment to slice 1-10% of the primary beam: electrostatic septum

In order to get a 1 to 10% portion of the primary beam from the 50-GeV accelerator, a special equipment called an electro-static septum is necessary. The intensity of the primary proton beam from the accelerator is so strong that heat deposition and its effects to the equipments have to be highly taken into account, because a large amount of heat deposition can be expected at the septum. More R&D works should be necessary to estimate the beam loss and to finalize the design including selection of the material for the septum.

3.3 Beam line configuration and optics

An example of the beam line configuration and optics is shown in Fig. 3. Secondary particles produced at the SM1 target with the angle of 4° are captured by a set of quadrupole magnets, and then transported to the experimental target which is located 120m downstream. In this example, 10 GeV/c particles are transported with the acceptance of 0.2 msr %. The bore radius of the quadrupole magnets are 10 cm or less, and the maximum magnetic field at the surfaces is about 9 kgauss or less.

Transportation of the primary beam is more straightforward. The emittance of the primary beam, even if a portion of it is sliced by a beam stealer, is small enough that it can be transported without loss at the beam line elements.

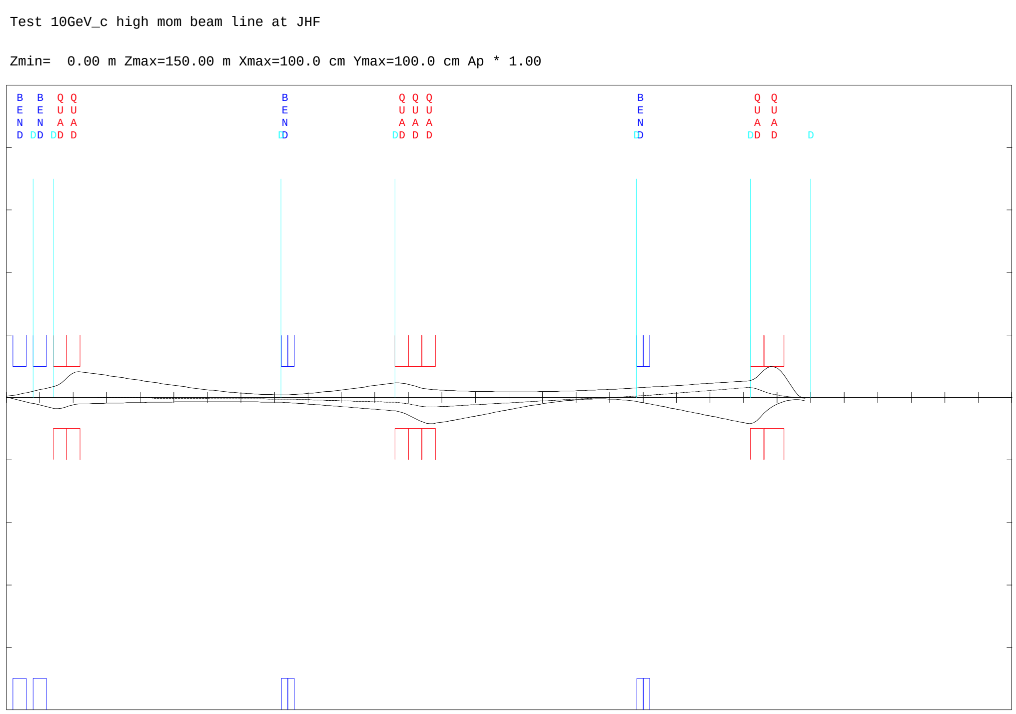

Figure 3: Example of the beam line configuration.

3.4 Yield estimation

The primary beams can go through the beam line without significant beam loss, and thus the beam intensity is the same as at the separation point of SM1. Of course the technical issues for the beam separation device, such as an electrostatic septum, have to be solved to obtain 10^{12} primary protons per second, as discussed in a previous section.

In order to get secondary beam intensity at the experimental site, the production cross sections of the secondary particles by proton-copper reactions are estimated from the Sanford-Wang formula [1]. This formula is a result of a fit to the experimental data of incident proton energy of up to 33 GeV, and the cross sections at 50 GeV might be different, which should be measured by ourselves. Please note that at the beginning of the operation of the 50-GeV synchrotron, the slow-extracted beam energy will be 30 GeV. Throughout the estimation, the production angle of the secondary particles is assumed to be 4°, the acceptance of the beam line is 0.2 msr %, and the distance from SM1 to the experimental target is 120 m. These values are consistent with the beam line consideration in the previous section. Tables 2 and 3 shows the estimated production cross sections and particle yields per 10^{14} incident protons for 30-GeV and 50-GeV incident protons, respectively. From the very beginning of the operation of the 50-GeV synchrotron with 30-GeV proton beams and even lower beam intensity, for example 10% of the design value (= 10^{14} per second), high momentum pion beams with the intensity of the order of 10^6 per second can be obtained, as shown in Tab. 2. In the phase 2 of the construction, the slow-extracted beam energy will become 50 GeV, where higher production cross sections of the secondary particles are expected. As shown in Tab. 3, more than 5×10^7 high momentum pions per second can be expected, while more than 10^5 kaons and antiprotons per second are estimated.

In order to obtain more secondary beams especially with higher momenta, it is important to collect secondary particles at smaller production angle, such as 2°. When a beam separation device for smaller angle with wide acceptance, such as a septum magnet, can be developed after R&D studies, more secondary beams ($> 10^8$ pps) with higher momenta are expected.

Table 2: Production cross sections of secondary particles from the 30-GeV proton-copper reactions and yields. The production angle of 4 degree and the beam line acceptance of $(\Delta p/p)\Delta\Omega = 0.2 msr\%$ were assumed. The yields per 10^{14} incident protons are shown.

	Momentum (GeV/c)	$d\sigma/dpd\Omega$ (mb/sr/GeV/c)	Yield at SM1	Yield at 120m
π^+	5	1400	3.7×10^7	2.4×10^7
π^+	10	210	1.1×10^7	8.9×10^6
π^-	5	1000	2.6×10^7	1.7×10^7
π^-	10	130	6.7×10^6	5.4×10^6
K^+	5	130	3.3×10^6	1.3×10^5
K^+	10	28	1.4×10^6	2.8×10^5
K^-	5	61	1.6×10^6	6.4×10^4
K^-	10	7.0	3.6×10^5	7.2×10^4
$\bar{p}$	5	11	2.8×10^5	2.8×10^5
$\bar{p}$	10	1.1	5.7×10^4	5.7×10^4

4 Summary

We would like to propose construction of a multi-purpose high-momentum beam line. The beam line should handle primary beams of the momenta up to 51 GeV/c, and secondary beams of about 15 GeV/c. The origin of the beam line should be at the SM1 separation point. In order to obtain 10 to 100 ppm of the primary beams, a beam line equipment called a "beam stealer" can be used. For the full primary beams, such as heavy ion beams and polarized proton beams, a conventional magnet can be used to take the beam to this beam line. For the secondary beams, a 2% loss metal target can be used. With this beam line, the high momentum secondary beams of more than 10^6 particles per second can be expected at the beginning of the operation of the 50-GeV synchrotron. After R&D studies, more than 10^8 high momentum secondary beams and 10^{12} primary proton beams (1 to 10% of the full proton beam) are expected in the future.

Table 3: Production cross sections of secondary particles from the 50-GeV proton-copper reactions and yields. The production angle of 4 degree and the beam line acceptance of $(\Delta p/p)\Delta\Omega = 0.2 msr\%$ were assumed. The yields per 10^{14} incident primary protons are shown.

	Momentum (GeV/c)	$d\sigma/dpd\Omega$ (mb/sr/GeV/c)	Yield at SM1	Yield at 120m
π^+	5	3700	9.5×10^7	6.2×10^7
π^+	10	930	4.7×10^7	3.8×10^7
π^-	5	3700	9.5×10^7	6.2×10^7
π^-	10	700	3.6×10^7	2.9×10^7
K^+	5	440	1.1×10^7	4.4×10^5
K^+	10	120	6.2×10^6	1.2×10^6
K^-	5	220	5.7×10^6	2.3×10^5
K^-	10	56	2.9×10^6	5.8×10^5
$\bar{p}$	5	53	1.4×10^6	1.4×10^6
$\bar{p}$	10	16	8.4×10^5	8.4×10^5

In addition to the above beam line, a beam line of the momenta up to about 4 GeV/c should be constructed from the T1 target, in order to accommodate requirements of high intensity kaon beams.

References

[1] J. L. Sanford and C. L. Wang, BNL report No 11299 & 11479 (1967).