THE BOOSTER SYNCHROTRON UTILIZATION FACILITY AT KEK

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1. Overall Summary

The Booster Synchrotron Utilization Facility (BSF) was established to provide a pulsed neutron source facility (KENS), a meson physics research facility (BOOM) and high-energy proton and neutron beams for medical and biological purposes (PARMS). According to schedule, on June 18, 1980, the BSF which had been under construction since 1978, came into operation. Preliminary surveys indicated that the production of thermal, epithermal and cold neutrons from the tungsten target for the neutron scattering experiments was satisfactory. On July 16, one month after delivery of the first beam, protons from the booster synchrotron were switched to the meson experimental area and the emergence of pulsed meson and muon beams from a 6 m long 5 Tesla superconducting solenoid was confirmed. Initial operation of the new Booster facility during the one and half months up to the end of July was devoted to confirmation and adjustment of various design parameters. Adjustment and improvement of the apparatus will be continued during the second half of this year and the new facility will be regularly open to users from the beginning of the next fiscal year. The proposal for medical use of the booster beam, which was submitted to the government through the University of Tsukuba, was approved last

April and construction of the facility will start shortly.

2. Booster Synchrotron and its Injector System

Operation of a 20 Hz rapid-cycling 500 MeV Booster Synchrotron as an injector for the 12 GeV proton synchrotron commenced in December 1974. Design parameters of the synchrotron are listed in Table 1. The design goal of a beam intensity of 6×10^{11} protons per pulse was achieved in June 1977. During the summer of 1979 the vacuum chamber of the main synchrotron was replaced and the maximum beam intensity in the main ring exceeded 4×10^{12} protons per pulse the last May. A consequence of the increased acceptance of the main ring is that the booster synchrotron operates with above the initial design intensity. During the initial shared operation of the booster with the main ring synchrotron 47 pulses every 2.4 seconds were delivered to BSF as shown in Fig. 1. The effective rate for BSF was thus about 16 Hz.

Conversion of the injection scheme in the booster synchrotron from the present multi-turn injection to charge exchange injection with a H^- ion beam is under consideration. By this new scheme, not only will the ordinary proton beam intensity be increased, but the acceleration of polarized proton beams will also become possible. The development of a H^- ion source and design of such an injection system for the booster synchrotron are now in progress. Measurements of the proton beam life time in the multi-traverse through a 120 $\mu g/cm^2$ carbon foil stripper set in the booster ring indicate that it will be possible to inject a H^- ion beam of 150 turns into the booster. This would give rise to an estimated circulating beam current of about 1.5 A in the booster just after the injection process for a 15 mA H^- injected ion beam. The circulating current is only about 0.4 A with the present multi-turn injection scheme. A trial H^- ion source on a test stand is now delivering a 15 mA H^- ion beam for a duration of 150 μsec.

3. Proton-Beam Line

Fig. 2 shows the layout of Booster Synchrotron Utilization Facility including the booster synchrotron and the beam line to the facility. The length of the beam line from the booster to the neutron production target is about 150 m. The beam line consists of two parts; the beam-dump line and a new line extending from the beam dump to BSF. A pulsed bending magnet on the injection course to the main ring separates the proton-beam pulses of 50 nsec from the main ring injection beam and directs them towards the beam dump located outside the accelerator enclosure. The beam-dump line makes a vertical detour around a cable pit containing feeder lines for the main ring magnets and it is designed to fulfill achromatic conditions in the vertical plane at the exit from the vertical bending magnet located just before the beam dump. The proton beam may be switched in one of three directions by another pulsed switching magnet situated about 40 m downstream from the beam dump. If the magnet is switched off the beam hits directly the spallation neutron target. By supplying power to the magnet the beam may be switched either to the meson experimental area or to the secondary proton beam line for medical purposes. The beam line contains several π-sections in addition to the achromatic and matching sections. At the exit from the matching section, which is located downstream from the beam-dump line, the beam is focussed into an appropriate size for the

respective production target to which it is transfered through π-sections.

All the evacuated beam pipes including the bellows and gaskets in the BSF beam line are manufactured from aluminium alloy with the exception of the ceramic chamber and stainless steel squared bellows of the pulsed switching magnet. The residual radioactivity in aluminium induced on exposure of the 500 MeV proton beam is much lower than that in stainless steel.

The monitor system for the beam line consists of fifteen beam-profile monitors and ten intensity monitors inclusive of those on the beam-dump line. It is possible to measure the beam emittance and twiss parameters without disturbing the beam transportation.

During normal operation of the accelerator, 38 proton-beam pulses within each main ring repetition period of 2.4 sec are available for BSF, each 50 nsec beam pulse containing about 6×10^{11} protons. These pulses are distributed to the pulsed neutron source facility, the meson physics research facility and medical use in accordance with the prescribed program.

4. Pulsed Neutron Source Project

Construction of the pulsed neutron source (KENS), which utilizes the pulsed proton beam from the KEK 500 MeV booster synchrotron, started in 1977. Neutron beams ranging in energy from eV to meV are provided by spallation in a tungsten target and using moderators of polyethylene at room temperature and solid methane at 20 K, and a Be reflector about 200 kg in weight. The target assembly is placed at the centre of a large biological shield consisting of a heavy-concrete fixed shield and a movable section composed of iron and concrete blocks. Thirteen neutron beam holes are installed in the biological shield. Each of these, except for three supplying cold neutrons to the guide tubes, is equipped with a 0.9 m long iron shutter. The three neutron guide tubes which transport cold neutrons to the cold neutron experimental area have a 9 m long curved section with a cross section of 20 x 50 mm^2 and a radius of curvature of 820 m. Ni float glass is used for the neutron reflector in the guide tube, which transmits the neutrons with wave lengths more than 4 Å. A tail cutter is also installed at the exit of the cold neutron beam hole to admit only those neutrons with wave lengths less than 12 Å. Five spectrometers for thermal, epithermal and cold neutron scattering experiments and a data acquisition system have already been designed and constructed. The installed spectrometers are as follows: Small Angle Neutron scattering instrument (SAN), TOF spectrometer with Optical Polarizer (TOP), Low energy Large Analyzer Mirror spectrometer (LAM), Multi Analyzer Crystal neutron spectrometer (MAX) and High Intensity Total scattering spectrometer (HIT). The emphasis of the research conducted at the pulsed neutron source will be on condensed matter in non-equilibrium states, transient phenomena and the structures of liquid and amorphous materials under normal and extreme conditions such as high pressure or low temperature.

5. Meson Physics Research Facility (BOOM)

In 1978, the Meson Science Laboratory was established in the Faculty of Science, Univ. of Tokyo. Representing a branch of that laboratory, the facility called BOOM (Booster Meson facility) has been established as one of the three major projects of BSF (Meson,

Neutron and Medical). The final goal of the BOOM project is to create a meson experimental facility and research program based on the maximum use of the unique pulsed time structure provided by BSF. μSR studies using pulsed muons are the central area of study. Fig. 3 shows the layout of the meson experimental area.

The main apparatus in BOOM is a pulsed muon channel, which is characterized by a superconducting solenoid representing the $\pi\mu$ decay section. The pion injector consists of a quadrupole triplet and a single bending magnet placed at a zero degree take-off angle with 75 mstr acceptance. A Be target 3 cm in diameter and 12 cm long is normally used for pion production. The superconducting solenoid, which is 6 m long, 12 cm internal diameter and with a central field of 5 T, is indirectly cooled by supercritical He. In the extraction channel of the muon beam, a QQ-B-Q-B-QQ type achromatic scheme is applied. This provides good beam focussing properties. The number of μ^+ produced in the preliminary experiment was estimated to be 2.5 x 10^4/pulse or 5 x 10^5/sec. For the μ^- intensity, this number should be divided by a factor of 3. The comparison between the negative muon intensities at the muon channels of the major meson factories as shown in Fig. 4. The average intensity of our channel is relatively low but still competitive. However, the instantaneous intensity is really huge, easily 3 orders of magnitude larger than that of the LAMPF stopped muon channel.

The newly completed pulsed μSR facility is therefore quite satisfactory in both intensity and quality. There are several types of μSR experiments which can be studied effectively only by this facility and, in addition to μSR measurements, there are also other experimental projects to which our pulsed muon beam may be effectively applied.

Table 1 Design Parameters of KEK Booster

Structure	
Type of Focusing	Combined-Function
Focusing Order	FDFO
Energy and Magnetic Field	
Max. Kinetic Energy	500 MeV
Max. Field at Equilibrium Orbit	11.018 kG
Injection Kinetic Energy	20 MeV
Injection Field at Equilibrium Orbit	1.969 kG
Repetition Rate	20 Hz
Physical Dimensions	
Average Radius	6 m
Circumference	37.70 m
Bending Radius	3.3 m
Number of Magnets	8
Orbit Parameters	
Profile Parameter	3.664 m^{-1}
Number of Betatron Oscillation per Revolution	
Horizontal	2.2
Vertical	2.3
Average Momentum Compaction Factor	0.1877
Total Transition Energy over Rest Energy	2.308
Transition kinetic Energy	1.23 GeV
Maximum and Minimum β	
$\beta_{H.max}$	3.40 m
$\beta_{V.max}$	8.25 m
$\beta_{H.min}$	1.48 m
$\beta_{V.min}$	1.55 m
Maximum Dispersion Function	1.40 m
Apertures of Magnets and Acceptance	
Useful Semi-Aperture of Magnets	
Horizontal	50 mm
(Good Field Region	63 mm)
Vertical	30 mm
Height of Magnet Gap at Equilibrium Orbit	76 mm
Acceptance at 20 MeV	
Horizontal	56 mm.mrad
Vertical	10 mm.mrad
Emittance at 500 MeV	
Horizontal	112 mm.mrad
Vertical	15 mm.mrad
RF Acceleration	
Revolution Frequency	
at Injection	1.617 MHz
at Final Energy	6.031 MHz
Intensity Estimation	
Incoherent Space Charge Limit	2.6×10^{12} ppp*
Coherent Space Charge Limit	4.3×10^{12} ppp
Design Intensity	6×10^{11} ppp
(Final Goal	1.1×10^{12} ppp)

*ppp : protons/pulse

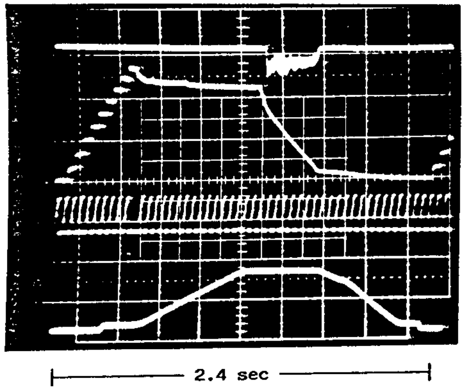

Fig. 1 Proton beam currents
in MR synchrotron and booster synchrotron

1st trace:	Extracted proton beam from MR
2nd trace:	Circulating proton beam in MR
3rd trace:	Circulating proton beam current in the booster
4th trace:	Magnetic field of MR

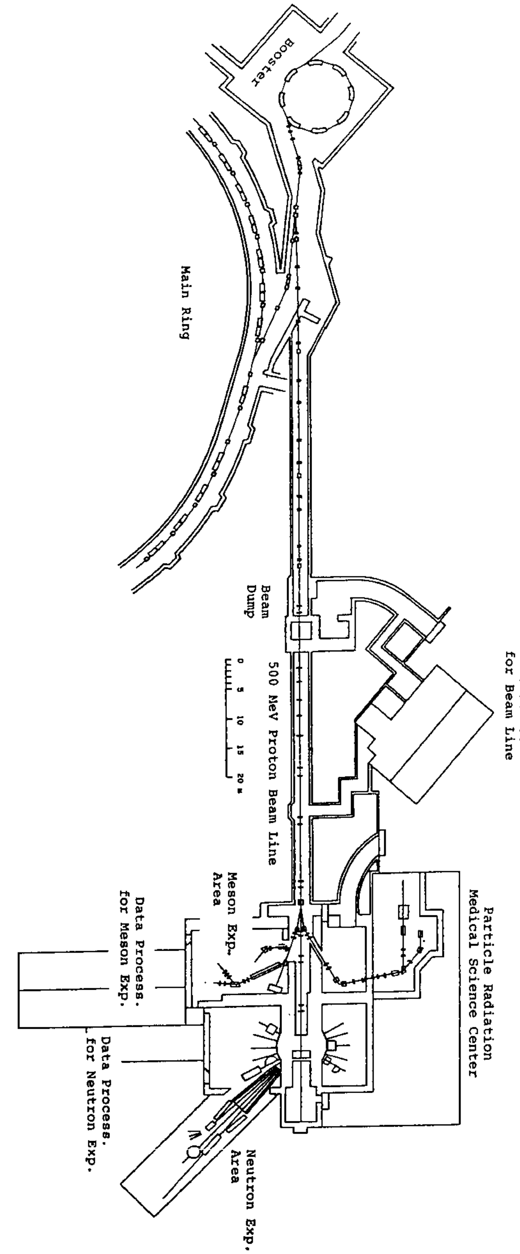

Fig. 2 Layout of Booster Synchrotron Utilization Facility and booster synchrotron

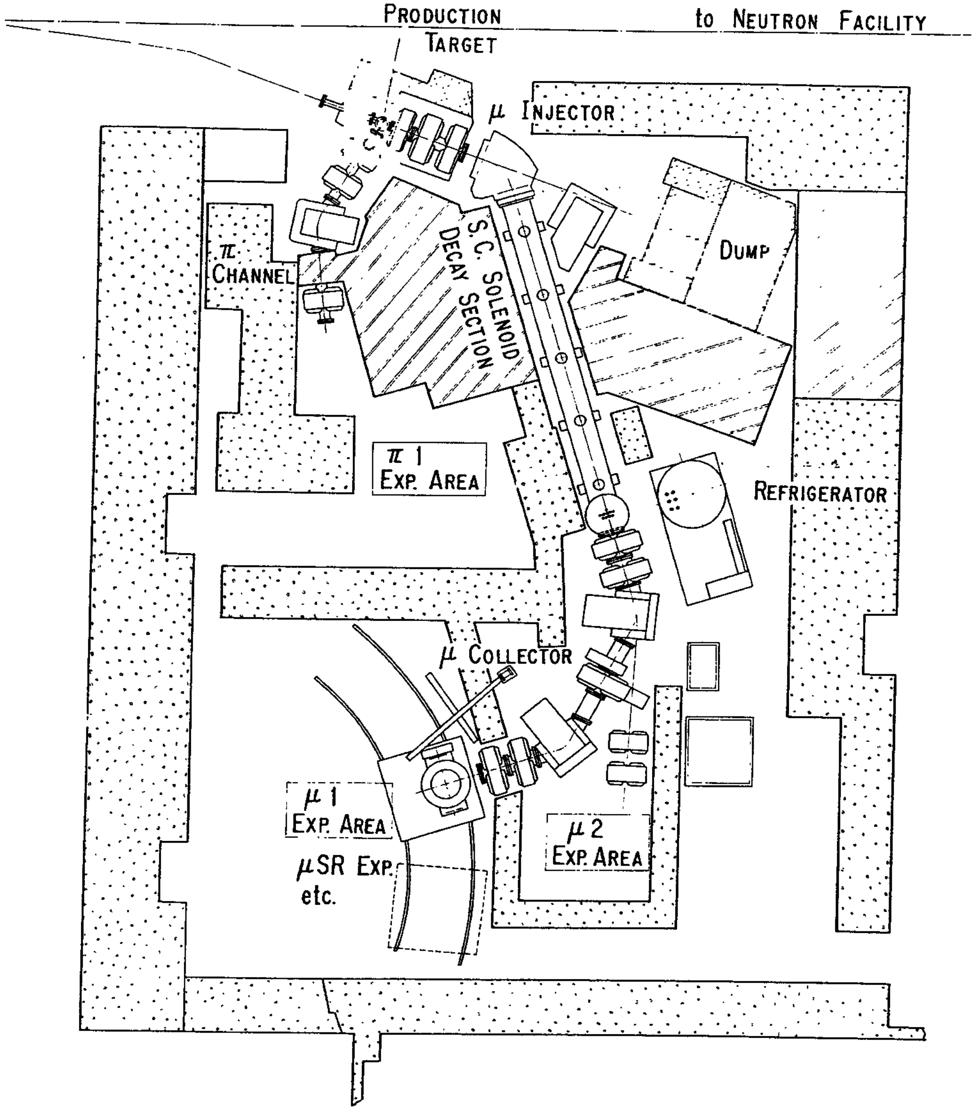

Fig. 3 Layout of the meson experimental area

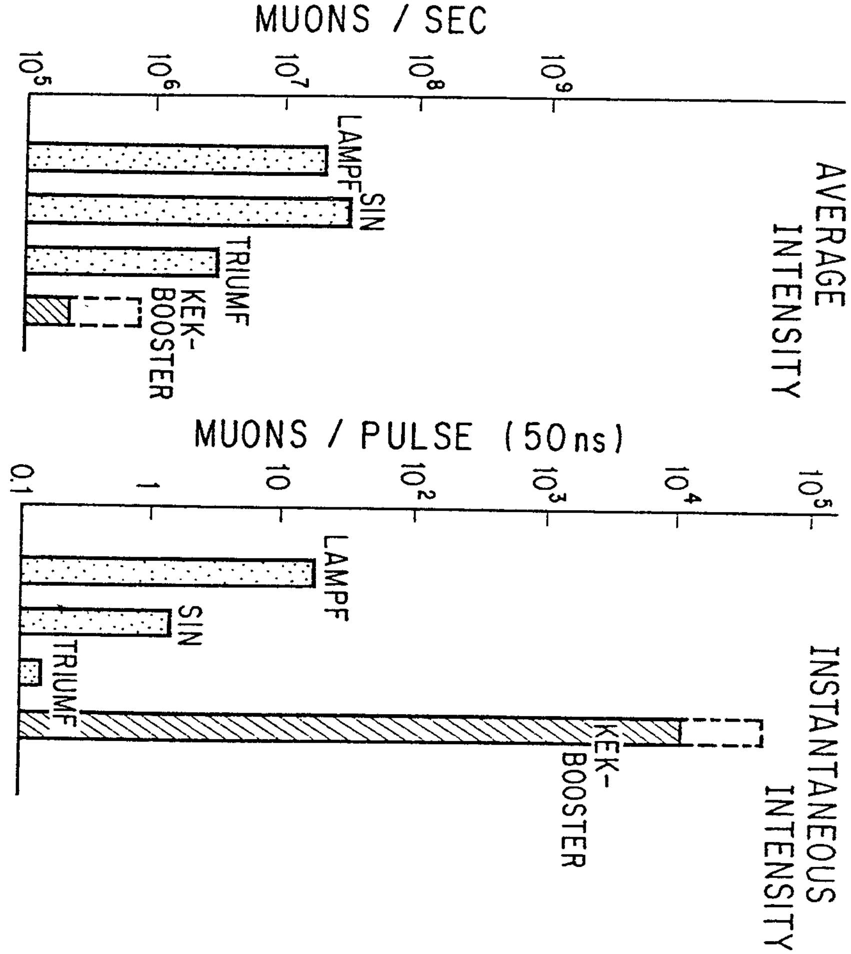

Fig. 4 Negative muon intensity at the major meson factories. Design value is shown by broken line.