RIKEN RI-Beam Factory Project

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Abstract

The "RI-Beam Factory" project has been proposed for upgrading the RIKEN Accelerator Research Facility. In 1997 fiscal year, the construction budget for the first phase of this project has been approved. In the factory a cascade of a K930-MeV ring cyclotron and a K2500-MeV superconducting ring cyclotron will be constructed as an energy booster of the existing ring cyclotron. The final energy will be increased up to more than 100 MeV/nucleon even for very heavy ions. By the projectile fragmentation these energetic heavy-ion beams will be converted into RI (radioisotope) beams covering over the whole range of atomic masses and with energies of several hundreds MeV/nucleon. Moreover, this factory will include a next generation of the multi-use experimental storage rings (MUSES) consisting of an accumulator-cooler ring, a booster synchrotron ring and double storage rings. The MUSES will enable us to conduct various types of unique colliding experiments.

1 Introduction

The RARF (RIKEN Accelerator Research Facility) has a heavy-ion accelerator complex consisting of a K540-MeV ring cyclotron (RRC) as a main accelerator and two different types of injectors: a frequency-variable Wideröe linac (RILAC) and a K70-MeV AVF cyclotron (AVF). The facility provides heavy-ion (HI) beams over the whole atomic mass range and in a wide energy range from 0.6 MeV/nucleon to 135 MeV/nucleon. One of the remarkable features of this facility is capability of supplying light-atomic-mass RI (radioisotope) beams with the world-highest level of intensity which are produced by means of the projectile fragment separator, RIPS [1].

In order to further promote experimental programs utilizing RI beams, the RARF undertakes the construction of "RI Beam Factory". The bird's eye view of its layout is illustrated in Fig. 1. The factory is aimed at providing RI beams covering over the whole atomic-mass range with very high intensity in a wide energy range up to several hundreds MeV/nucleon.

2 The Heavy-ion Accelerator Complex for High-intensity RI Beam Generation

The factory utilizes the "projectile fragmentation" to generate RI beams of intermediate energies. To enable the efficient generation of such RI beams covering the whole atomic masses, are needed high-intensity primary heavy-ions, up to uranium ions, with the energies exceeding 100 MeV/nucleon. In order to realize those energies, a cascade of an intermediate-stage ring cyclotron (IRC) with K=930 MeV and a superconducting ring cyclotron (SRC) with K=2500 MeV will be constructed as an energy booster of the existing RRC. In addition, to realize enough intensity, we will upgrade the RILAC which serves as the initial-stage accelerator by introducing a new pre-injector and a charge-state multiplier (CSM). This accelerator complex will possess

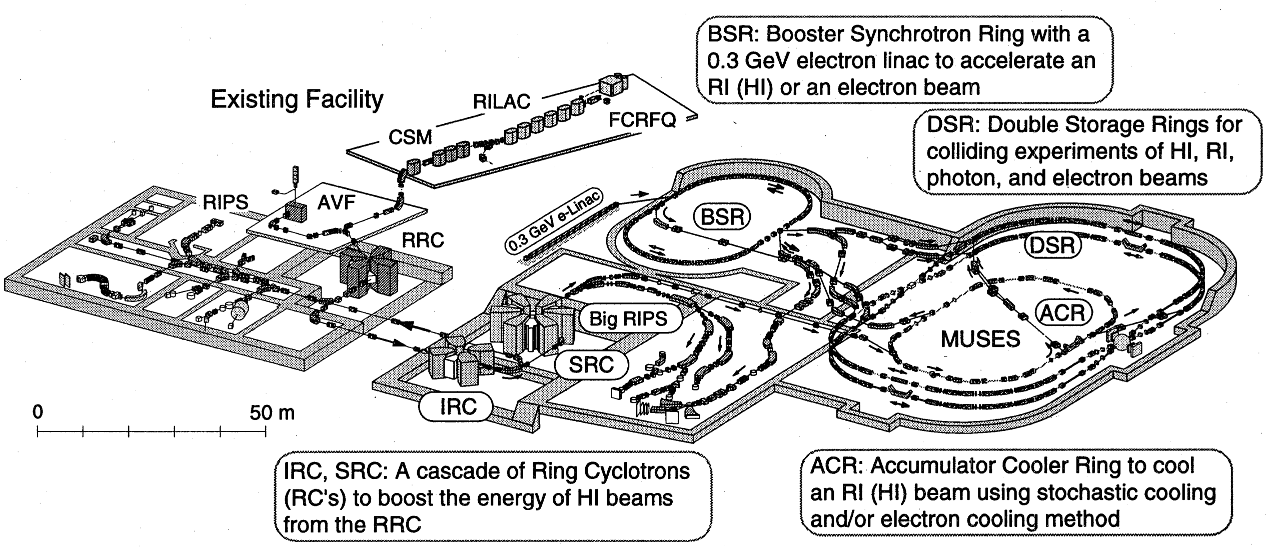

Fig. 1 Bird's eye view of "RI-Beam Factory" layout.

such performance that a 100 MeV/nucleon uranium beam with the intensity over 1 pμA is obtainable.

2.1 Pre-injector for RILAC

In order to upgrade the RILAC performance in the beam intensity by one or two orders of magnitude, its new pre-injector system consisting of a frequency-tunable folded-coaxial RFQ linac (FC-RFQ) equipped with an 18-GHz ECR ion source (ECRIS-18) has been developed. In the recent acceleration tests, the FC-RFQ has successfully covered HI beams in the energy-mass region required, and the beam transmission efficiency of about 90 % at the maximum was obtained. In addition, high-intensity highly-charged ion beams have been produced by the ECRIS-18.

2.2 CSM

The CSM consists of an accelerator, a charge stripper and a decelerator. Its functions are to produce higher charge state of ion beams by further increasing the stripping energy and to reduce their magnetic rigidity by decelerating them to the initial energy. With this device the magnetic rigidity of the RILAC beam with a most-probable charge state can be reduced to the acceptable value of the RRC even when the injection velocity into the RRC is increased. The accelerator and decelerator are of a type of frequency-tunable IH linac whose operational radio-frequencies are twice as that of the RILAC to double an acceleration gradient.

2.3 IRC-SRC

The IRC's maximum energies are 127 MeV/nucleon for light ions up to around Ar, 102 MeV/nucleon for Kr^{30+}, and 58 MeV/nucleon for U^{58+}. The minimum energy is 25 MeV/nucleon. In the SRC the maximum energies are increased to 400 MeV/nucleon for light ions up to around Ar, to 300 MeV/nucleon for Kr^{30+}, to 150 MeV/nucleon for U^{58+} and to 100 MeV/nucleon for U^{49+}. The minimum energy is 60 MeV/nucleon.

In this two-stage cyclotron scheme the simultaneous utilization of the HI beams is possible in both of the existing experimental facility and the new facility, when part of the IRC beam is charge-stripped and is transferred back to the existing facility.

We have undertaken the fabrication of a full-scale model sector magnet of the SRC without a yoke to verify the mechanical and cryogenic design. The superconductors for the main and trim coils have already been complete. This task is scheduled to be finished by the spring of 1998.

The details of the IRC-SRC system is described in ref. [2].

3 Multi-Use Experimental Storage Rings (MUSES)

The MUSES (Multi-USe Experimental Storage rings) consists of an Accumulator-Cooler Ring (ACR), a Booster Synchrotron Ring (BSR) with an injector electron linac and Double Storage Rings (DSR). It will be installed downstream from the SRC and an RI beam separator, Big-RIPS.

The ACR functions for accumulation and cooling of RI (HI) beams, and is also used for atomic and molecular physics experiments with a cooler electron beam. The BSR works solely for the acceleration of RI (HI) and electron beams. The DSR permits various types of unique colliding experiments: RI (HI) - HI merging or head-on collisions; collisions between electron and RI (HI) beams; and collisions of RI (HI) beams with a high brilliant X-ray emitted from an undulator which is inserted in one ring of the DSR.

The details of the MUSES appears in the papers in this proceedings.

3.1 Production of RI Beams

The SRC's HI beams irradiate a production target and are converted into RI beams through the projectile fragmentation. RI beams generated are the mixture of various RI's; and therefore, they will be purified by means of momentum and charge-state selection at Big-RIPS.

Figure 2 shows the time structure of the SRC's beam which will be produced by the future pre-injector of the RILAC. The structure consists of a series of a short pulse (SP) with high peak current (100 pμA at the maximum) and a long pulse (LP) with low peak current (1pμA at the maximum). These pulses are split by the pulse magnet system of the Big-RIPS; and the RI beam generated by the SP primary beam is transferred to the ACR, and those by the LP are transferred to the first-phase experimental hall.

The SP RI beam is transported to the injection point of the ACR along the length of 70 m. At the end point of transport line, a debuncher system will be installed to reduce the momentum spread of this beam.

3.2 Accumulation and Cooling of RI beams in ACR

RI-beam SP bunches coming from the Big-RIPS are injected into the ACR by means of the multi-turn injection.

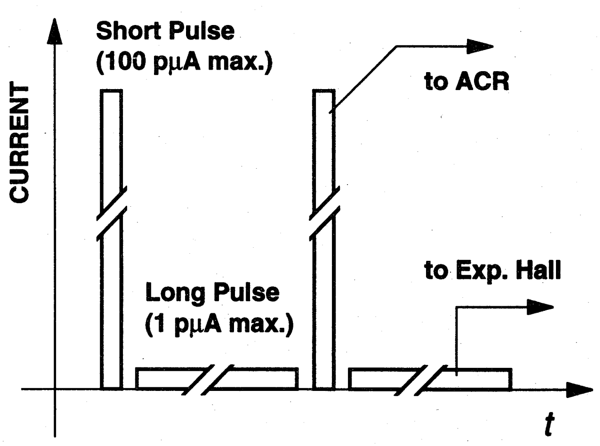

Fig. 2 Time structure of SRC's beam.

Then the rf-stacking associated with the beam cooling is performed. Momentum cooling continuously works during the rf-stacking. This process is repeated at intervals of the rf-stacking time of 30 ms plus the cooling time depending on the RI-beam property.

Simulation study for both of the electron cooling and the stochastic cooling of RI beams was done. As a result, it turned out that the stochastic cooling is much faster than the electron cooling. This is due to the property of the RI beam: the intensity is rather weak; and both of the momentum and emittance spreads are large.

The RI beam accumulated in the ACR decays with its own intrinsic life time. The number of the RI ions stored in the ACR after the period of life time is determined by the balance of the supply rate and the decay rate. The space charge limit was also considered in the estimation of the maximum number of RI ions stored in the ACR. This limit, however, becomes effective only for RI ions neighboring on the stability line with high production rate.

The accumulated RI beams in the ACR will be fast extracted and one-turn injected into the BSR.

3.3 BSR

In the BSR, RI (HI) beams will be accelerated to the energy required for the experiment within 0.3 s, and then will be one-turn injected into the one ring of the DSR. The maximum energies are: e.g., 1 GeV/nucleon for $^{238}U^{92+}$, 1.5 GeV/nucleon for ions of charge-to-mass ratio (q/A) of 1/2 and 3.5 GeV for protons. The slow-extraction channel will also be prepared.

Electrons are accelerated up to 300 MeV by an electron linac and then injected to the BSR. The BSR boosts the electron energy up to 2.5 GeV at the maximum and supply them to the one ring of the DSR. The expected beam current in the DSR is about 500 mA.

Figure 3 shows the HI-beam acceleration performance by the RRC, ISR, SRC and BSR with expected beam intensity.

3.4 DSR

The DSR consists of vertically-stacked two rings of the similar specification. Each lattice structure takes the form of a racetrack to accommodate two long straight sections. These straight sections of one ring vertically intersect those of the other ring at two colliding points: one point is used for the collision between an RI beam and an electron beam at a collision angle of 20 mrad and the other for the merging of RI (HI) beams at a merging angle of 170 mrad. RF cavities and beam injection devices are placed at these long straight sections. Two short straight sections will be used for electron coolers to suppress the beam instabilities and to make a short-bunch ion beams.

The ring circumference is 269.6 m. The maximum energies of the stored beams are 1.0 GeV/nucleon for U^{92+} ions, 1.5 GeV/nucleon for light ions of q/A=1/2, and 3.5 GeV for protons.

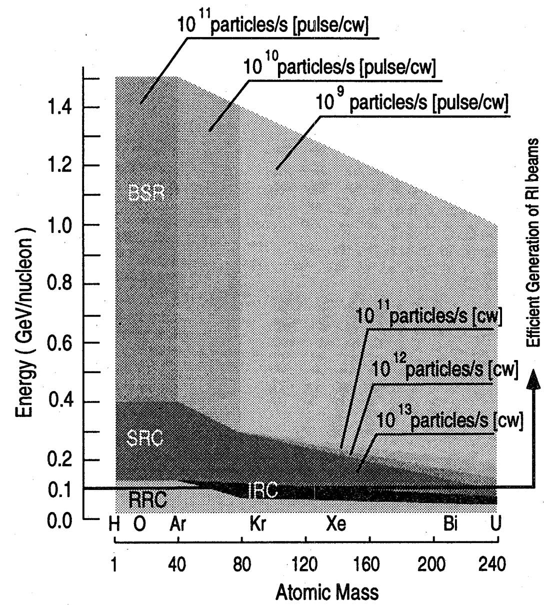

Fig. 3 Acceleration performance of HI beams of RRC, IRC, SRC, and BSR.

One of typical experiments conducted at the DSR is the collision of an RI beam with an electron beam to precisely measure charge-density distribution of unstable nuclei. In the experiment, one ring of the DSR will be filled with a high-current electron beam of nearly 500 mA with the energy of up to 2.5 GeV. The lattice of this electron ring is designed so that the emittance of electron beam is 10^{-6} π m·rad from the point of view of the luminosity and beam-beam effect. The parameters of the ion ring are different from those of the electron ring because of the difference between lattices of the colliding section in two rings. Another usage of an electron beam is to generate high brilliant X-ray by an undulator inserted in the electron ring. This X-ray will shine Li-like RI ions circulating in the other ring. By detecting fluorescence emission from the ions, new spectroscopy of unstable nuclei will be possible. For this purpose the electron-beam emittance is required to be as small as 10^{-8} π m·rad. This is achieved by forming the Double Bend Achromatic (DBA) system in the arc.

4 Construction Schedule

In the present schedule, the IRC, the SRC, the Big-RIPS and the experimental installation will be completed in 2002. The construction of the MUSES is planned to start in 2003 and to be fully finished in 2009.

REFERENCES

[1] T. Kubo et al., Nucl. Instrum. Meth., **B70** (1992) 309.
[2] A. Goto et al.: in this proceedings.