

# THE BEIJING ELECTRON-POSITRON COLLIDER AND ITS SECOND PHASE CONSTRUCTION

C. Zhang, J.Q. Wang for BEPC & BEPCII Teams, IHEP, CAS  
P.O.Box 918, Beijing 100039, China

## Abstract

The Beijing Electron-Positron Collider (BEPC) was constructed for both high energy physics and synchrotron radiation researches. As an  $e^+$ ,  $e^-$  collider operating in the  $\tau$ -charm region and the first synchrotron radiation source in China, the machine has been well operated more than 15 years since it was put into operation. As a collider, the peak luminosity of the BEPC has reached its design goal of  $5 \times 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$  at  $J/\psi$  energy of 1.55 GeV and  $1 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$  at 2 GeV respectively. The main parameters in the dedicated synchrotron radiation operation are:  $E=2.2\sim 2.5$  GeV,  $\varepsilon_x=80$  nm-rad at 2.2 GeV,  $I_b=140$  mA and the beam lifetime of 20~30 hours. As the second phase project of the BEPC, the BEPCII, has been approved with total budget of 640 million RMB. The construction is started in the beginning of 2004 and is scheduled to complete by the end of 2007. The BEPCII is a double ring machine with its luminosity goal of  $1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$  at 1.89 GeV, two orders of magnitude higher than present BEPC. The BEPCII will operate in the beam energy of 1-2.1 GeV so that its physical potential in the whole  $\tau$  and charm range is preserved, while the collider will be optimized at 1.89 GeV. The upgrading of the collider should also provide an improved SR performance with higher beam energy and intensity. The beam currents will be increased to 250 mA at  $E=2.5$  GeV for the dedicated synchrotron radiation operation of the BEPCII. Some key technologies, such as superconducting RF system, low impedance vacuum devices, superconducting micro-beta quadrupoles and etc., has been intensively studied in order to achieve the target of the BEPCII.

## BEPC PERFORMANCE

The BEPC was constructed for both high energy physics (HEP) and synchrotron radiation (SR) researches [1]. It has been well operated for more than 15 years. For high energy physics, the BEPC/BES accurately measured the mass of  $\tau$  lepton; carried out R-scan in the center-of-mass energy region of 2~5 GeV; collected the largest data sample of  $J/\psi$  and  $\psi'$  events in the world, with many interesting results being explored out in recent years [2]. As a synchrotron radiation facility, every year it serves more than 300 users from all over the country as the experimental platform doing research on physics, chemistry, material science, and biology etc.

The rich physics in the  $\tau$ -charm region calls for a much higher luminosity. Thus an upgrade project of BEPC, namely BEPCII, was proposed in 2000 and approved last year. It aims at a luminosity goal of two orders of magnitude higher than that of BEPC. On April 30 of this

year, BEPC completed its operation right on schedule and the construction of BEPCII started out.

## BEPCII DESIGN

The BEPCII will be operated in the beam energy region of 1.0-2.1 GeV so that its physical potential in  $\tau$ -charm range is preserved. The storage ring design is optimized at the beam energy of 1.89 GeV, and the details can be found in its design report [3].

### Upgrade strategy

The luminosity of an  $e^+e^-$  collider is expressed as

$$L(\text{cm}^{-2} \text{ s}^{-1}) = 2.17 \times 10^{34} (1+r) \xi_y \frac{E(\text{GeV}) k_b I_b (\text{A})}{\beta_y^* (\text{cm})}, \quad (1)$$

where  $r = \sigma_y^* / \sigma_x^*$  is the beam aspect ratio at the interaction point (IP),  $\xi_y$  the vertical beam-beam parameter,  $\beta_y^*$  the vertical envelope function at IP,  $k_b$  the bunch number in each beam and  $I_b$  the bunch current. So the strategy in BEPCII to enhance luminosity is to adopt micro- $\beta$  of 1.5cm at IP and to increase the bunch number with double ring scheme. The geometry layout of the storage rings for BEPCII is shown as Fig. 1.

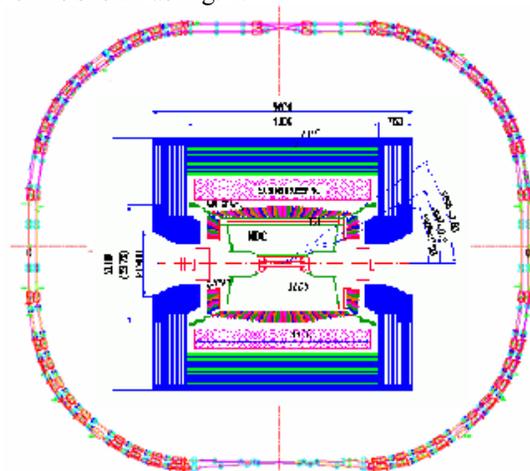


Figure 1: The layout of the double ring of the BEPCII.

The inner ring and the outer ring cross each other in the northern and southern IP's. The horizontal crossing angle between two beams at the southern IP, where the detector locates, is  $11 \text{ mrad} \times 2$  to meet the requirement of sufficient separation but no significant degradation to the luminosity. While in the northern IP, the two beam cross horizontally with angle of  $154.7 \text{ mrad} \times 2$  and a vertical bump is used to separate two beams, so that the optics of the two rings can be symmetric. For the dedicated synchrotron radiation operation of the BEPCII, electron

beams circulates in the outer ring, so in the northern IP, a bypass is designed to connect between outer ring and in the southern IP, a pair of bending coils in superconducting magnets serves this purpose.

In order to obtain a high average luminosity, top-off injection is adopted up to 1.89 GeV, and the positron injection rate should be higher than 50 mA/min.

### Beam Physics Design

Based on the strategy of the luminosity upgrading of the BEPC, the design for the BEPCII has been worked out. The beam physics issues are intensively studied on the aspects of lattice design, beam-beam interaction, and collective effects etc. [4].

The lattice for the collision mode is optimised to improve the dynamic aperture against various errors including misalignment and multipole field of magnets, meantime, with consideration on tuning the beta function to reduce the background due to Touschek effect. The lattice for SR mode is optimized on low emittance. Table 1 summarizes the main parameters of the BEPCII.

Table 1 Main Parameters of the BEPCII storage ring

Parameters	Unit	Collision	SR
Energy	GeV	1.89	2.5
Circumference	m	237.53	241.13
RF frequency	MHz	499.8	499.8
Harmonic		396	402
RF voltage	MV	1.5	3.0
Transverse tunes		6.53/7.58 6.53/5.58	8.28/5.18
Damping time	ms	25/25/12.5	12/12/6
Beam current	A	0.91	0.25
Bunch number		93	Multi
SR loss per turn	keV	121	336
SR power	kW	110	84
Energy spread		$5.16 \times 10^{-4}$	$6.66 \times 10^{-4}$
Compact factor		0.0235	0.016
Bunch length	cm	1.5	1.18
Emittance	nm-rad	144/2.2	120/
$\beta$ function at IP	m	1/0.015	–
Crossing angle	mrاد	$11 \times 2$	–
Bunch spacing	m	2.4	–
Beam-beam Parameter		0.04/0.04	–
Luminosity	$\text{cm}^{-2}\text{s}^{-1}$	$1.0 \times 10^{33}$	–

Beam-beam simulation is done to choose the best working point for high luminosity. It is found that when the fraction parts of the horizontal and vertical tunes are around 0.53/0.58, respectively, the luminosity is the highest. Simulation also shows that the crossing angle of  $11\text{mrad} \times 2$  is acceptable and beam-beam parameter of 0.04 is reasonable and reachable.

The single beam collective effects in BEPCII include the single and multi-bunch instabilities due to impedance as well as the ion effect in the electron ring and the electron cloud (ECI) in the positron ring. The main concern is the impedance control to alleviate bunch lengthening and to control ECI. A strict impedance

budget is set and antechamber with TiN coating is adopted against ECI. detailed studies can refer to [5].

The beam lifetime is around 3 hours, with the main limits coming from the beam-beam bremsstrahlung, Touschek effect and beam-gas interaction. With top-off injection, the maximum average luminosity can reach more than 60% of the peak luminosity.

## KEY TECHNOLOGIES & PROGRESS

There are many challenges on the key technologies and hardware for the BEPCII, such as injector upgrading, superconducting cavity and cryogenics system, low impedance kickers, magnet and power supply, vacuum system, IR, instrumentation and control etc. Some of them are introduced as follows.

### Injector Upgrading

The BEPC injector is a 202meter electron linac with 16 RF power sources and 56 S-band RF structures. The BEPCII requires the injector in two aspects. One is the full energy injection to the storage rings, i.e.  $E_{inj} \geq 1.89$  GeV, the other is that the positron intensity satisfies the required injection rate of 50 mA/min. To realize the full energy top-off injection up to 1.89 GeV, the klystrons are replaced with the new 45-50 MW devices and the modulators upgraded with new pulse transformer oil tank assembly, PFN, thyatron, charging choke and DC power supplies. In order to compensate the RF phase drift due to various factors, a RF phasing system is under development.

The technical measures taken for increase of positron intensity in the BEPCII injector can be summarise as: increase the  $e^-$  beam current on  $e^+$  target from 2.5A to 6A, the repetition rate from 12.5Hz to 50Hz, the bombarding energy for  $e^+$  from 140MeV to 240MeV, adopt new positron source to increase the yield from 1.4% to 2.7%, and two bunch injection scheme. Though the pulse length reduced from 2.5ns to 1ns, the total gain factor on the  $e^+$  intensity can be 20 times higher than BEPC.

All the hardware subsystems of BEPCII linac have been manufactured and will be installed in this summer after the dismantling of old facilities that started out on May 1. A new control system with on line software for beam optics tuning and orbit correction is ready. It's expected that commissioning of new linac can begin in September.

### Superconducting cavity and cryogenics

The superconducting scheme is chosen for its advantage on large accelerating gradient and well damped HOMs. Two superconducting cavities are needed in the BEPCII with one cavity installed on each ring to provide necessary RF voltage of 1.5 MV. The structure of the superconducting cavity is similar to that of KEKB style, but optimized at 499.8 MHz. Each cavity is powered with a 250 kW klystron. All the design has been finished and orders contracted.

The refrigeration capability of 300W is required for two superconducting cavities. Besides, it should provide cooling for the superconducting solenoid and the insertion magnets, so two 500W refrigerators is applied in the BEPCII. The final design is to be finished soon.

### *Injection Kickers*

In order to meet the challenges both on the filed uniformity and low coupling impedance, a modified slotted pipe kicker has been designed with the coating strips on ceramic bar instead of metallic plates as the beam image current return paths. A prototype is being made to test its feasibility.

### *Magnets*

Due to limited space in the BEPC existing tunnel, except the old BEPC magnets reused, both the longitudinal and transverse size of the newly built magnets should be as small as possible. In addition, the magnets are designed giving room for the antechamber on horizontal plane. Prototypes for bending magnet, quadrupole and sextupole have been made to verify that the multipole effect due to the small size of the magnet can be minimized to acceptable level. Since the distance between magnet installed on the ring is small, measurement will be done to check the interfere between magnets.

### *Vacuum System*

The BEPCII poses two challenges to the vacuum system, one is the vacuum pressure, and the other is the impedance. The design vacuum pressure of BEPCII is  $8 \times 10^{-9}$  Torr in the arc and  $5 \times 10^{-10}$  Torr in the IR. Antechamber is chosen for both electron and positron rings. For positron ring, concerning the ECI, the inner surface of the beam pipe in the arc should be coated with TiN to reduce the secondary electron yield (SEY). A lab has been set up to study the coating process. The recent measurement on the samples shows that SEY can be reduced to less than 1.3. Further study and improvement is under way.

### *IR and Superconducting Insertion Magnets*

The design of IR has to accommodate competing and conflicting requirements from the accelerator and the detector. Many equipments including magnets, beam diagnostic instruments, masks, vacuum pumps, and experiment detector must coexist in a very small region. Figure 6 demonstrates a 3D sketch of the half IR.

A mock-up of IR installation is carried out to demonstrate the designed procedure on the support, installation, background shielding, vacuum pumping and many other issues in the IR are carefully studied.

A special pair of superconducting IR magnets are designed with main and skew quadrupole, compensation solenoid and dipole coils to squeeze the  $\beta$  function at IP, compensating the detector solenoid and serve as the bridge connecting outer ring in SR operation, respectively.

The superconducting magnet is designed and made collaborating with BNL.

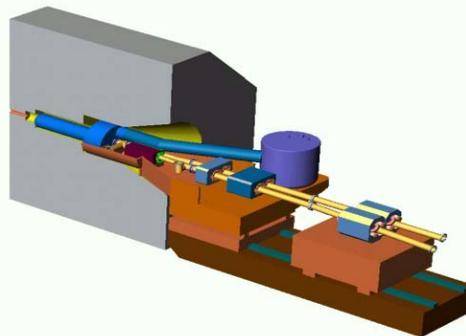


Figure2: A 3D sketch of the IR.

Some special warm bore magnet in IR as septum bending magnet and two in one quadrupole have been manufactured, the magnetic field measurement results confirms the design.

### *Instrumentation and Control*

The instrumentation system consists of 136 beam position monitors (BPM's), 2 DCCT's, 2 bunch current monitors and 2 synchrotron radiation monitors. Besides, transverse and longitudinal feedback systems are equipped in order to damp beam instabilities

The control system will be based on the EPICS environment to provide a friendly man-machine interface for operators. A prototype system is being created to build the system structure and develop the basic application program.

## **BUDGET AND SCHEDULE**

The budget of the BEPCII project is estimated as 640 million RMB. The project is scheduled to complete by the end of 2007.

## **SUMMARY**

The BEPC has been well operated with many exciting HEP and SR results for 15 years. The BEPCII is designed with a double-ring structure and its design luminosity is two orders of magnitude higher than the present BEPC. Some key technologies are being developed in order to achieve the scientific goals of the BEPCII.

## **REFERENCES**

- [1] S.X.Fang and S.Y.Chen, Proc. of the 14-th Int. Conf. on High Energy Acc., 1989, p51.
- [2] BES Collaboration, Phys. Rev. Lett. 91, 022001 (2003).
- [3] BEPCII Group, BEPCII Design Report, IHEP-Proceedings, Aug. 2001.
- [4] L.M Chen, et al, Workshop on e+ e- in the 1-2 GeV Energy Range: Physics and Accelerator Prospects, Sept. 2003, Alghero (SS), Italy
- [5] J.Q. Wang, et al, these Proceedings.