BEPCII : STATUS AND PROGRESS

BEPCII Team
Institute of High Energy Physics, CAS
P.O.Box 918, Beijing 100039, China

Abstract

The status and progress of second phase construction of the Beijing Electron-Positron Collider (BEPC), i.e. the BEPCII, are reported. The design luminosity of the BEPCII is $1\times10^{33}cm^{-2}s^{-1}$ at 1.89 GeV with a double-ring scheme. The performance of the BEPCII as a synchrotron radiation source will also be improved with the expected beam current of 250mA at 2.5 GeV. Some key technologies are being developed in order to achieve the goal of the project.

1 INTRODUCTION

The BEPC was constructed for both high energy physics (HEP) and synchrotron radiation (SR) researches [1]. The BEPC-accelerators consist of a 202 m long electron-positron linac injector, a storage ring with circumference of 240.4 m and, in connection with each other, 210 m transport lines. There are two interaction points in the storage ring. A general-purpose detector, the Beijing Spectrometer (BES), is installed in the south interaction region. The Beijing Synchrotron Radiation Facility (BSRF), equipped with 4 insertion devices and 12 beamlines, is flanking the east and west of the southern areas of the storage ring. Figure 1 illustrates the layout of the BEPC.

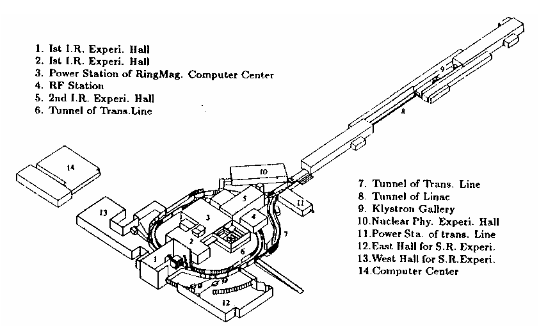

Figure 1: Layout of the BEPC

As a unique e^+-e^- collider operating in the τ and charm region and a first synchrotron radiation source in China, the machine has been well operated for 15 years.

The beams are injected, stored, accelerated and collided in the storage ring. Figure 2 displays the layout of the BEPC storage ring, and Figure 3 shows the beam currents vs. time in a day for J/ψ operation.

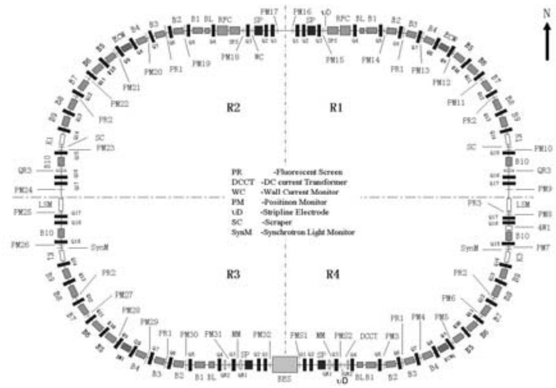

Figure 2: Layout of the BEPC storage ring

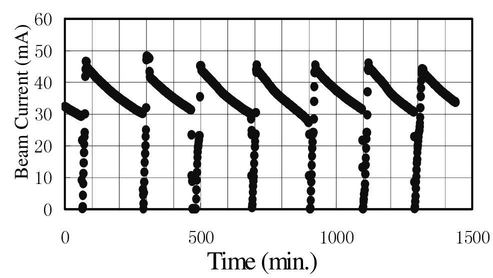

Figure 3: Beam currents vs. time for J/ψ operation

A narrow peak was observed near the 2 times of the proton energy in the $M(p\bar{p})$ distribution for $J/\psi \rightarrow \gamma p\bar{p}$ decays using the BES-II 58 million J/ψ events [2], shown in Figure 4. This is a significant result, although it is still too early to determine if it is a proton-antiproton bond state or multiple quark state.

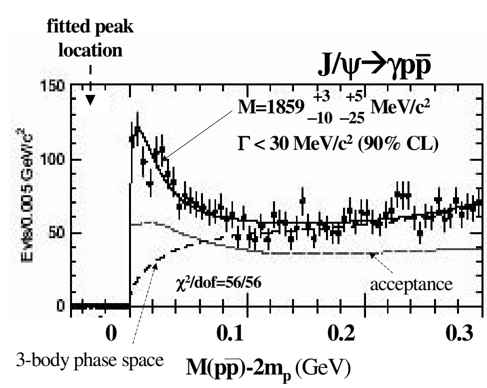

Figure 4: The new peak observed near 2M(pp)

The physics opportunity in the charm-τ region calls higher luminosity. The BEPCII, with a luminosity goal of two orders of magnitude higher than the present BEPC, is its natural extension. Detailed design of the BEPCII accelerators can be found in its design report [2].

2 BASIC DESIGN

The BEPCII will be operated in the beam energy region of 1.0-2.1 GeV so that its physical potential in τ and charm range is preserved. As the physics is concentrated at the J/ψ (3097), ψ(3686), ψ(3770) and nearby, the collider is optimized at the beam energy of 1.89 GeV.

2.1 Luminosity from BEPC to BEPCII

As a measure of the event production rate, luminosity is one of the most important parameters in colliders. The luminosity of a e^+-e^- collider is expressed as

$$L(\mathrm{cm}^{-2}\mathrm{s}^{-1}) = 2.17\times10^{34}(1+r)\xi_y \frac{E(GeV)k_b I_b(\mathrm{A})}{\beta_y^*(\mathrm{cm})}, \quad (1)$$

where $r=\sigma_y^*/\sigma_x^*$ is the beam aspect ratio at the interaction point (IP), ξ_y the vertical beam-beam parameter, β_y^* the vertical envelope function at IP, k_b the bunch number in each beam and I_b the bunch current.

With the parameters of BEPC, E = 1.55 GeV, ξ_y = 0.04, β_y^* = 5cm, k_b = 1 and I_b = 22 mA, and assuming $r = \sigma_y^*/\sigma_x^* \approx \beta_y^*/\beta_x^*$ = 0.042, the luminosity of the BEPC is calculated from eq. (1) as $0.62\times10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, which agrees well with the measured value of $0.5\times10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at 1.55 GeV. Table 1 describes the strategy of the luminosity upgrading from the BEPC to the BEPCII.

Table 2: Luminosity strategy from BEPC to BEPCII

Parameters	BEPC	BEPCII
Beta function at IP β_y^* (cm)	5.0	1.5
Bunch number k_b	1	93
Beam-beam parameter ξ_y	0.04	0.04
Current per bunch I_b (mA)	35	9.8
Luminosity gain L_{BEPCII}/L_{BEPC}	1	96

In order to obtain a high duty factor of the collision, the injection time should be shorter than half an hour. The injector should be capable of the full-energy top-off injection up to 1.89 GeV, and the positron injection rate should be higher than 50 mA/min. As the machine will also be operated as an SR source, the upgrade of the collider should also provide an improved SR operation performance with higher beam energy and intensity. The SR beam ports should be reserved for BSRF and more beam lines will be equipped in the quadrant I of the storage ring tunnel, where electron beams are stored in the outer ring.

2.2 Main Parameters

Based on the strategy of the luminosity upgrading of the BEPC, the design for the BEPCII is worked out. Table 2 summarizes the main parameters of the BEPCII.

Table 3: The main parameters of the BEPCII

Optimised Beam Energy E		GeV	1.89
Circumference C		m	237.53
Bunch Number k_b			93
Bunch Current I_b		mA	9.8
Beam Currents I_{beam}	Colliding	mA	910
	SR		250 (2.5GeV)
RF Frequency f_{RF}		MHz	499.8
RF Voltage per ring V_{RF}		MV	1.5
Beta Function at IP β_x^*/β_y^*		cm	100/1.5
Emittance $\varepsilon_x/\varepsilon_y$		nm·rad	144/2.2
Bunch Length σ_{z0}/σ_z		cm	1.3/1.5
Energy spread σ_e			5.16×10^{-4}
Bunch Spacing S_b		m	2.4
Impedance $\|Z/n\|_0$		Ω	< 0.7
Tune $\nu_x/\nu_y/\nu_z$			6.53/7.58/.034
Damping Time $\tau_x/\tau_y/\tau_z$		ms	25/25/12.5
Beam-beam Parameter ξ_x/ξ_y			0.04/0.04
Crossing Angle ϕ_c		mrad	11×2
Luminosity L		$\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1×10^{33}

2.3 The Double-ring Structure

A substantially higher performance could be reached with the double-ring option for much more bunches are allowed to be collided, as seen in Table 2. However, the space for the two rings in the existing BEPC tunnel needs to be carefully checked. Figure 5 shows the layout of the double ring arrangement in the BEPC tunnel. The inner ring and the outer ring cross in the northern and southern IP's. A bypass connects the outer ring in the northern interaction regions (IR) and a pair of bending coils in superconducting magnets serves this purpose in the southern IR, so that electron beams can be circulated in the outer ring for the dedicated synchrotron radiation operation of the BEPCII. The design beam currents for synchrotron radiation are 250 mA at 2.5 GeV.

The mock-up in the BEPC tunnel was carried out to examine the feasibility of the double-ring installation. Figure 6 pictures one section of the mock-up of the double ring installation in the existing BEPC tunnel as a part of the inner ring.

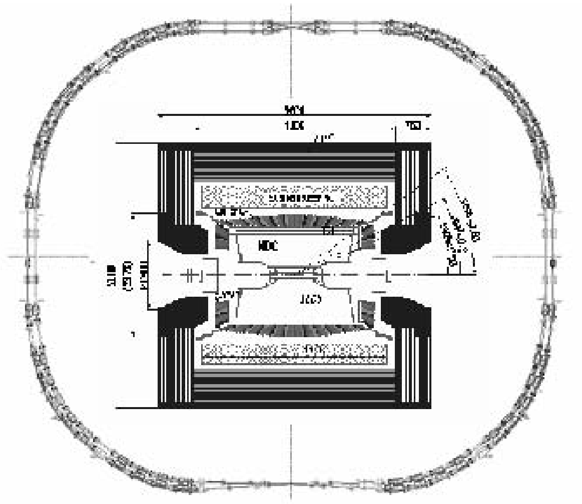

Figure 5: The layout of the double ring of the BEPCII

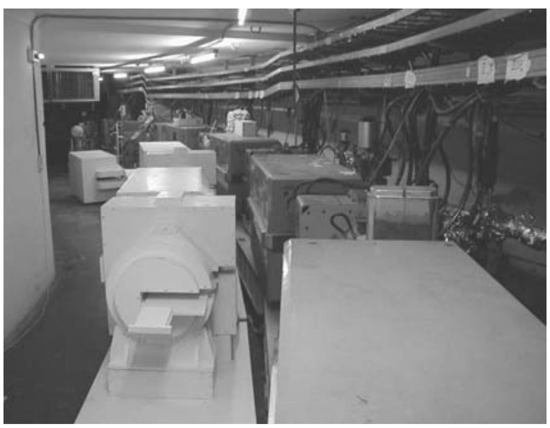

Figure 6: Mock-up of two rings in the BEPC tunnel

The conclusions of the moke-up are as follows:

- No principle problems are found for the transportation, installation, mounting and dismount of the magnets.
- The inner ring magnets will cover the existing monuments for survey and alignment. New monuments will be fixed on the wall of the tunnel.
- The antechamber of the positron ring needs to be carefully designed to fit the crucial space between two rings;
- The cable system, the cooling-water system, the pressure-air system and others need to be rearranged.

2.4 Impedance and Collective Effects

Control of the bunch length and impedance is one of the crucial issues for the success of the micro-β scheme in the BEPCII. There are experimental and theoretical evidences that the bunch length in a collider should be smaller or comparable to the β-function at IP. The bunch length in the BEPCI is about 5 cm in the operation condition of I_b ~20 mA, V_{rf} ~0.6 MV at 1.55 GeV. In order to operate the collider with micro-β scheme of $\beta_y^* = 1.5$ cm, the bunch length σ_l in the BEPCII should be less than 1.5 cm. With the 500 MHz superconducting cavities of V_{rf} = 1.5 MV, the natural bunch length σ_{l0} = 1.1 cm. However, the finite impedance due to the discontinuity of the vacuum pipes in the storage ring will make the bunch lengthening with its intensity. The bunch length will be increased due to potential well distortion and microwave instability. The threshold of microwave instability is

$$I_{th} = \frac{\sqrt{2\pi}\alpha_p \frac{E}{e}\sigma_{e0}{}^2\sigma_{l0}}{R\left|\frac{Z}{n}\right|_{eff}}, \qquad (2)$$

where α_p is the momentum compaction factor, E the energy of the beam, σ_{e0} and σ_{l0} the natural rms energy spread and natural rms bunch length respectively, R the mean radius of the ring, $|Z/n|_{eff}$ the longitudinal effective coupling impedance. It predicts the instability threshold of 0.97Ω for the design current of 9.8 mA.

In order to make the impedance $|Z/n|_{eff}$ smaller than 0.97 Ω, all the vacuum components such as bellows, kickers, separators, BPM's, masks, connectors, valves, pumps, and SR beam ports must be carefully checked and studied. The computer code of MAFIA is applied to compute the impedance of vacuum components in comparison with measurements. According to the above impedance budget, the total inductance of BEPCII is about 28.9 nH, corresponding to $|Z/n|_0$~0.23Ω. The design study shows that it is possible to control the impedance under the threshold impedance of the microwave instability if the vacuum chamber is rebuilt by adopting the state of art technology in the BEPCII. The computation of the wakefield of the whole ring and simulation for bunch lengthening are in progress.

The coupled bunch instabilities due to the beam-cavity interaction is estimated based on the high order mode (HOM) data of KEKB superconducting cavities. The growth rate of the dangerous modes of the coupled bunch instability with N_b= 99, I_b = 9.8 mA are τ_{rise} = 12.8 ms (longitudinal m = 0) and τ_{rise} = 26.6 ms (transverse m = 1), which are close to the SR damping time of the BEPCII at 1.89 GeV of $\tau_x/\tau_y/\tau_z$ = 25/25/12.5 ms.

The real part of the impedance may cause the resistive wall instability. The major part of the vacuum chamber of the BEPCII is made of aluminium. The computation with the code of ZAP indicates that the most dangerous mode of the resistive wall instability in the BEPCII has the growth time of 1.6 ms for ν_y=7.9 with N_b= 99, I_b= 9.8 mA at the present design tunes. The estimation is done with the 99 uniformly distributed bunches in the ring which is considered as the up limit of the instability for 93 bunches with a small gap in the BEPCII. The instabilities can be handled with a feedback system.

The electron and positron beams will circulate in the separated rings in the BEPCII, so the foreign particle caused instabilities such as ion trapping, fast ion instability, dust effect and electron cloud instability, are concerned. The theoretical and experimental studies on these instabilities in the BEPCII are in progress.

The head-on beam-beam parameter of 0.04 is demonstrated in the BEPCI. A finite-crossing angle of ±11 mrad is adopted for the IP of the BEPCII. With this crossing angle, the strong parasitic beam-beam interactions can be avoided for the 2.4 m bunch spacing. The electron and positron bunches are further than $10\sigma_x$ separated at the parasitic collision points, which seem large enough. However, the sophisticated beam-beam simulation with a crossing angle needs to be carried out in further detail.

The beam lifetime determines the duty factor of the storage ring operation. Many coherent and incoherent effects will influence the beam lifetime. In the BEPCII, the major effects are considered as beam-gas interaction, beam-beam bremsstrahlung, Touschek effect and quantum effect. The overall beam lifetime is estimated as about 2.7 hours, and then the optimized collision time is calculated as 1.0 hours with the maximum average luminosity $\langle L \rangle_{max}=0.5\times10^{33}\,cm^{-2}s^{-1}$.

More detailed discussions on the accelerator physics issues in the BEPCII are given in [3].

3. KEY TECHNOLOGIES AND SUBSYSTEMS

Number of key technologies and hardware subsystems need to be developed for the BEPCII, including injector upgrading, superconducting RF system, low impedance kickers, vacuum system, superconducting insertion magnets and interaction region and some others [4].

3.1 Iinjector Upgrading

BEPC injector is a 202meter electron linac with 16 RF power sources and 56 S-band RF structures. The positron production system is located at down stream of second RF power source.

The BEPCII requires the injector in two aspects. One is the full energy injection to the storage ring, i.e. $E_{inj}\geq$ 1.89 GeV, the other is that the positron intensity satisfies the required injection rate of 50 mA/min. In order to realize the full energy top-off injection up to 1.89 GeV, the present-used 34 MW klystrons shall be replaced with the new 45-50 MW devices. The present modulators will be upgraded with new pulse transformer oil tank assembly, PFN, thyratron, charging choke and DC power supply.

The technical measures taken for increase of positron intensity in the BEPCII injector are listed in Table 3.

The new positron target is shown in Figure 7 and the positron production system is shown in Figure 8. The system test will be carried on soon.

Table 3: The technical measures for increasing positron intensity

Technical measure	Intensity Factor
To increase e^- beam current on e^+ target I_G=2.5A↗ 6A	2.4
To increase the repetition rate f_r=12.5Hz ↗ 50Hz	4
To enhance bombarding energy for e^+ E_c = 140MeV↗240MeV	1.7
New positron source of higher yield η =1.4%↗ 2.7% ($e^+/e^-\cdot$GeV)	1.9
Two bunches injection：n_b=1↗ 2	1.6
Reduction of pulse length：T = 2.5ns↘1ns	0.4
Total intensity enhancement factor	19.8

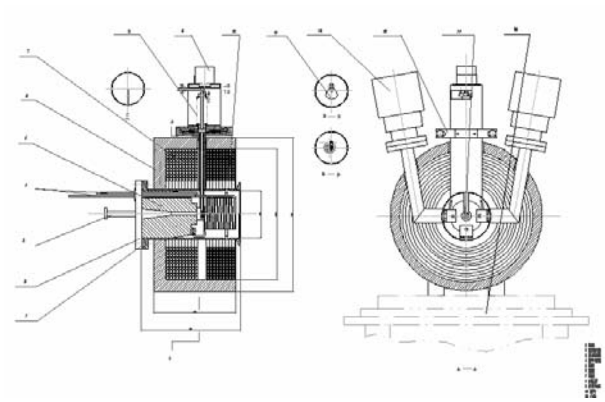

Figure 7: The new positron source design

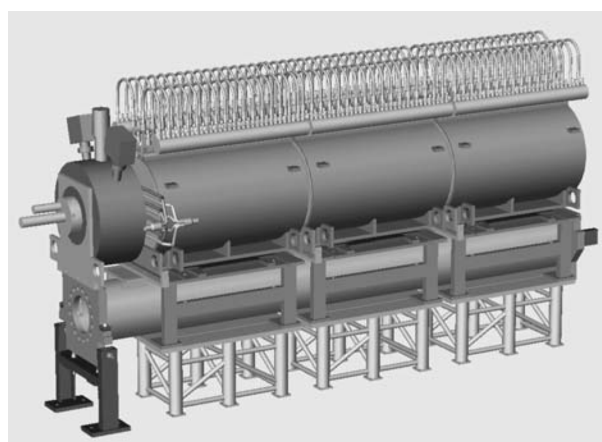

Figure 8: The positron production system

3.2 500 MHz Supercunducting RF System

The BEPC has been operating with 200 MHz normal conducting cavities. As mentioned in the previous sections, in order to meet the design goal of higher luminosity with shorter bunch length, one needs to increase RF frequency and enhance accelerating voltage.

Normal conducting and superconducting RF cavities are compared for the BEPCII. The superconducting scheme is chosen for its larger accelerating gradient, smooth structure and large beam port, transmitted-out of HOMs and low RF power consuming. Two superconducting cavities will be used in the BEPCII providing 2×1.5 MV RF voltage. The cavities will be powered with two 250 kW RF transmitters. The low lever RF control is sketched in Figure 9.

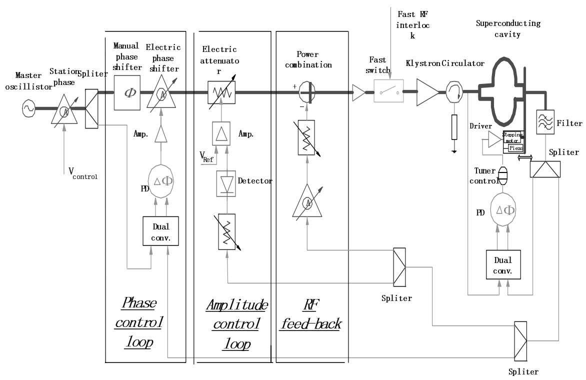

Figure 9: The sketch of the low lever RF control

The refrigeration capability of 300W is required for two supercunducting cavities. Two 500W refrigerators will be applied in the BEPCII. One is for the cavities and another is for micro-β insertion supercunducting magnets and detector solenoid.

3.3 Injection Kickers

The study has shown that the kickers in BEPC are one of major sources of the coupling impedance in BEPC, where single turn air coils are located inside vacuum chambers of the kickers.

Two schemes were considered for the BEPCII kickers. One is ferrite magnet outside the vacuum with ceramic beam pipe; another is the slotted-pipe magnet inside the vacuum tank. We choose a modified slotted pipe kicker design with the coating strips on ceramic bar instead of metallic plates as the beam image current return paths. With this design, the balance between the field uniformity and the beam impedance is advantaged. The computed magnetic field distribution of the slotted-pipe kickers is illustrated in the figure 10.

The inductance of the string type kickers is computed as 2.2 nH for two kickers, larger than the ceramic pipe case. However, it is still a fraction of the total inductance of 28.9 nH per ring.

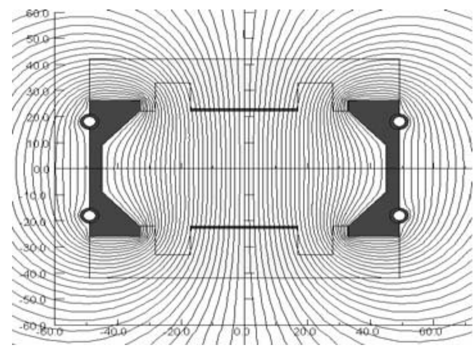

Figure 10: Cagnetic field distribution of the kickers

3.4 Magnets and Power Supplies

The double-ring structure of BEPCII requires doubling the number of magnets. There are all together 363 magnets of different types, including 44 old and 48 new bends, 28 old and 89 new quads, 72 new sextuples, 22 old and 54 new correctors. The optimised energy is 1.89GeV, while the magnets can operate normally in 2.1GeV. Due to the space limitation of BEPC exist tunnel, the size of inner ring magnets should be as small as possible. The magnets are designed giving room for the antechamber on horizontal plane. The cooling water pressure drop on all designed magnets is kept below 6 kg/cm^2, same as it is in BEPC. There are 40 girders in the arcs of each ring, where the magnets and other components are mounted. The layout of the installation is shown in the Figure 11.

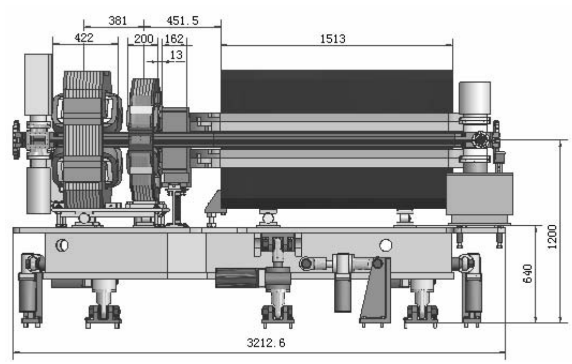

Figure 11: The magnets mounted on a girder

More magnets need more power supplies, while the flexibility of the lattice design needs another factor of two power supplies. The total number of power supplies increases from 90 of present BEPC to 327 of BEPCII, where 4 power supplies are used for the bends, 123 for the quads, 36 for the sextupoles, 14 for the special IR magnets, 11 for IR superconducting magnets and 134 for correctors.

In order to mount the additional power supplies in the existing rooms, the new power supplies should be compact by using the improved technology. Two types of

DC power supplies, i.e. switch-mode (Chopper, PWM converter and zero voltage switching converters) and thyristor phase-controlled type (12 and 6 phases rectifiers), are applied in BEPCII. The strategy for the BEPCII power supply system is to make the best use the existing devices, to apply the industry standard products and easy for operation and maintenance. The electro-magnetic interference problem will be carefully considered in the design especially for the switch-mode power supplies. The stability test of the chopper (Buck converter) prototype is shown in Figure 12. It can be seen from the figure that the 24-hour stability of the power supply is around 1×10^{-5}.

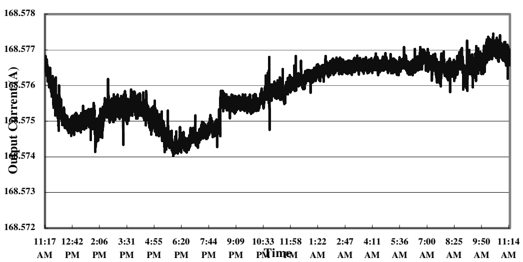

Figure 12: The stability test of the chopper prototype

3.5 Vacuum System

The BEPCII poses two challenges to the vacuum system, one is the vacuum pressure, and the other is the impedance.

The dynamic vacuum at a high beam current should satisfy the requirements of the sufficient beam lifetime, and the low background in the detector. The design vacuum pressure of BEPCII is 8×10^{-9} Torr in the arc and 5×10^{-10} Torr in the interaction region. The distributed ion pumps are used inside the bending sections, while in the straight sections lumped ion pumps and NEG are applied.

To reduce the impedance, the vacuum chamber should be as smooth as possible. Antechamber will be used for both electron and positron rings. Masks are placed upstream to such vacuum components as bellows in order to prevent them from exposure of synchrotron radiation. The figure 13 gives the antechamber with SR port and figure 14 shows the vacuum chamber in the bending magnet.

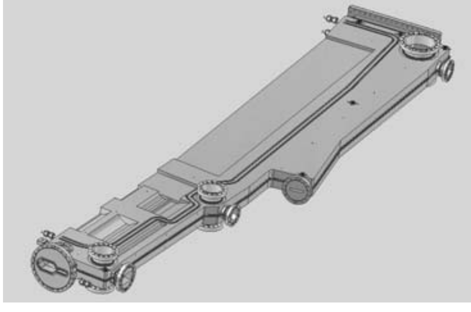

Figure 13: The antechamber with SR port

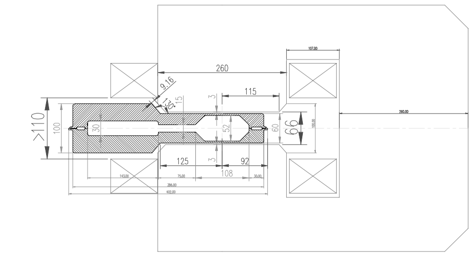

Figure 14: The vacuum chamber in a bending magnet

3.6 IR and Superconducting Insertion Magnets

The design of interaction region (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 15 shows the top-view of the interaction region.

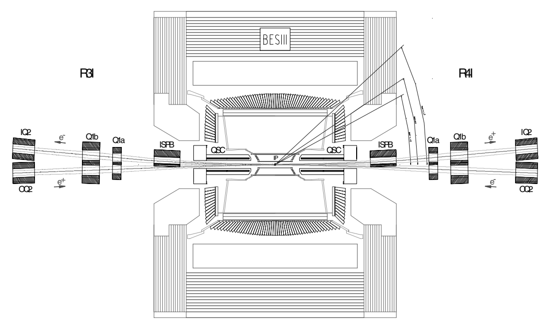

Figure 15: The top-view of IR

The support, installation, background shielding, vacuum pumping and many other issues in the IR are carefully studied. A mock-up of IR installation is being carried out. Figure 16 demonstrates a 3D sketch of half of the IR.

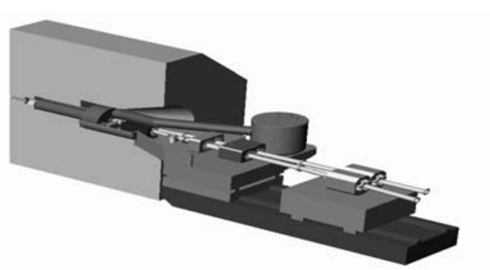

Figure 16: A 3D sketch of the IR

A pair of quadrupoles will be inserted into the BESIII detector to squeeze the β function at IP. Two types of insertion quadrupoles are considered, one is the permanent magnet and the other is the superconducting magnet. The permanent magnet is compact and no power supply is required. However, it is difficult to satisfy the wide operation range of the beam energy in the BEPCII using this type of magnet. The superconducting magnet can provide a strong and adjustable magnetic field. A special pair of superconducting IR magnets is designed with main and skew quadrupole, compensation solenoid and dipole coils. Figure 17 shows its profile.

Figure 17: The superconducting insertion magnet

3.7 Instrumentation and Control

Upgrade of the beam instrumentation system is an important part of the BEPCII. The system must provide precise and sufficient information about the beams so that machine operators can improve the performance of the collider by monitoring the beam behaviours, optimising the lattice parameters, correcting the closed orbit, increasing the injection efficiency, and enhancing the beam current and luminosity. Table 4 lists the lists types and quantities of monitors used in BEPCII storage rings.

Table 4: Beam monitors in BEPCII storage rings

Monitor		Quantity	Length（mm）
DCCT		2	350 (with flange)
SR light monitor		2	500 (with flange)
Fluorescent screen		8	160
BPM	e^+ ring	65	120
	e^- ring	65	120
	Special	2	30
Transverse kicker		4	500 (with flange)
Longitudinal kicker		2	500 (with flange)

The control system contains the computer control, the timing, the interlock and the communication subsystems. The storage rings and the injector should be operated in either the central control room or the local control room. Many new devices will be installed in BEPCII. The control system should be able to control and monitor all the equipment of the collider, including microwave systems, superconducting RF system, various power supplies, vacuum components, beam diagnostic system, interlock system and etc. The control system will be based on the EPICS environment to provide a friendly man-machine interface for operators. The architecture of the control system is shown in Figure 18.

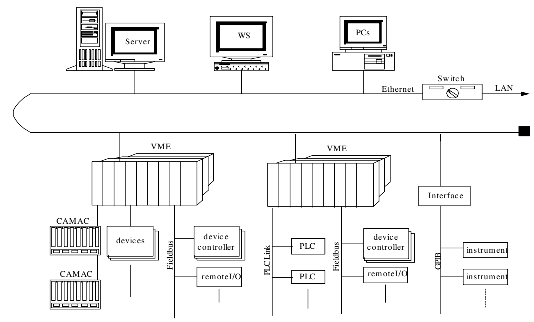

Figure 18: The architecture of the control system

4 BUDGET AND SCHEDULE

The budget of the BEPCII project is estimated as 640 million RMB. The project is scheduled to complete in 4 years after its approval. Figure 19 summarizes the expected milestones of the project.

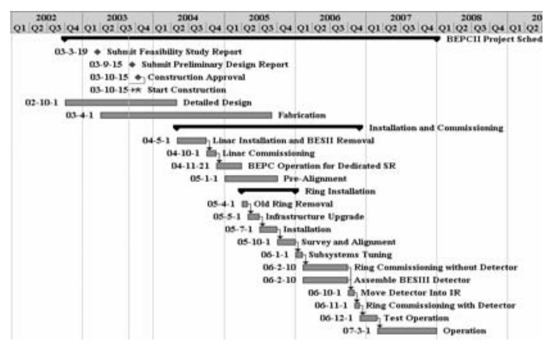

Figure 19 Schedule of the BEPCII project

5 SUMMARY

- The BEPC has been well operated with many exciting HEP and SR results for 15 years since it was put into operation in 1989.
- 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.

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