

# STATUS OF BEPC AND PLANS OF BEPCII

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## Abstract

The status of the Beijing Electron-Positron Collider (BEPC) and plans of its second phase construction, i.e. the BEPCII, are reported. The BEPC has been well operated for 12 years with many exciting high energy physics and synchrotron radiation research results since it was put into operation in 1989. As the near future plan, the BEPCII was approved in principle. The design luminosity of the BEPCII is  $1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$  @ 1.55 GeV with a double-ring scheme. The performance of the BEPC as a synchrotron radiation source will also be improved with the expected beam current of 150mA at 2.8 GeV and 250mA at 2.5 GeV. Some key technologies are being developed in order to achieve the goal of the BEPC II.

## 1 THE STATUS OF BEPC

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 9 beamlines and 12 experimental stations, is flanking the east and west of the southern areas of the storage ring. Figure 1 illustrates the layout of the BEPC.

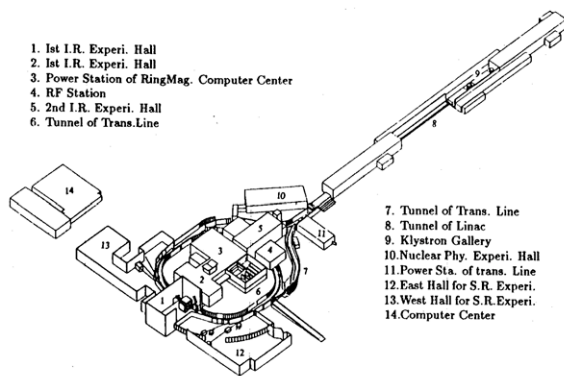


Figure 1: Layout of the BEPC

As a unique  $e^+e^-$  collider operating in the  $\tau$ /charm region and a first synchrotron radiation source in China, the machine has been well operated for 12 years. Table 1 lists its main parameters.

Table 1: Main parameters of the BEPC

Operation energy ( $E$ )	GeV	1.0-2.5
Injection energy ( $E_{inj}$ )	GeV	1.3
Circumference ( $C$ )	m	240.4
$\beta$ at IP ( $\beta_x^*/\beta_y^*$ )	cm	120/5
Tunes ( $\nu_x/\nu_y/\nu_z$ )		5.8/6.7/0.02 (HEP) 8.72/4.75/0.02 (SR)
Emittance ( $\epsilon_{x0}$ )	mm-mr	0.4 @ 1.55 GeV (HEP) 0.08 @ 2.2 GeV (SR)
RF frequency ( $f_{rf}$ )	MHz	199.53
Bunch number ( $N_b$ )		1×1 (HEP), 60-80 (SR)
Beam current ( $I_b$ )	mA	22 @ 1.55 GeV (HEP) 140 @ 2.2 GeV (SR)
Beam-beam param. $\xi_y$		0.04
Beam lifetime $\tau$	hrs.	6-8 (HEP), 20-30 (SR)
Luminosity	$\text{cm}^{-2} \text{s}^{-1}$	$5 \times 10^{30}$ @ 1.55 GeV $1 \times 10^{31}$ @ 2 GeV

The beams are injected, accumulated, stored 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  $J/\psi$  operation.

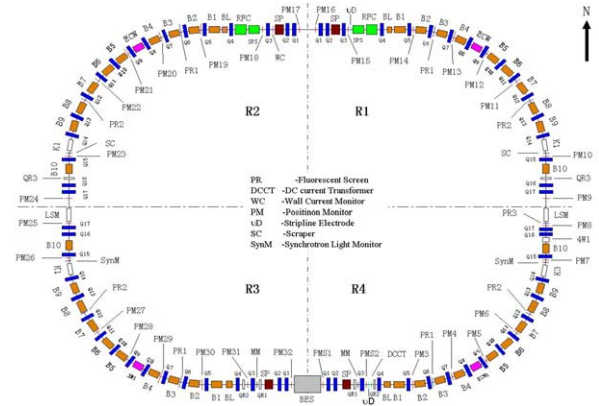


Figure 2: Layout of the BEPC storage ring

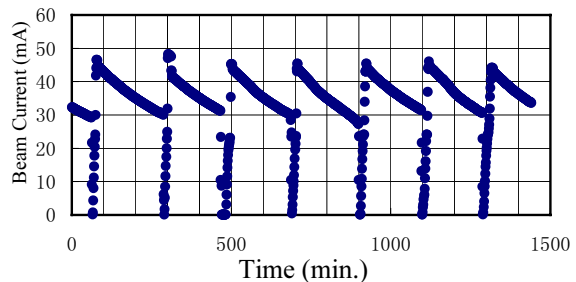


Figure 3: Beam currents vs. time for  $J/\psi$  operation

As a result of the successful operation, the BEPC/BES has collected a largest data sample of  $J/\psi$  events in the world (see Figure 4); while the R-scan in the center-of-mass energy region of 2–5 GeV improves its accuracy from 15% to 7%, which has significant impacts on such important physics parameters as  $\alpha_s$ ,  $g-2$  and predicted Higgs mass (see Fig. 5) [2], [3].

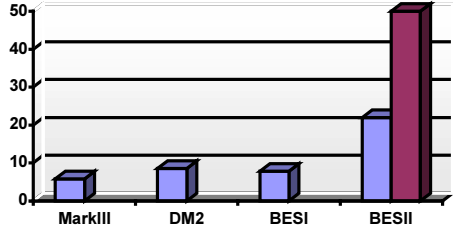


Figure 4:  $J/\psi$  events collection in the world

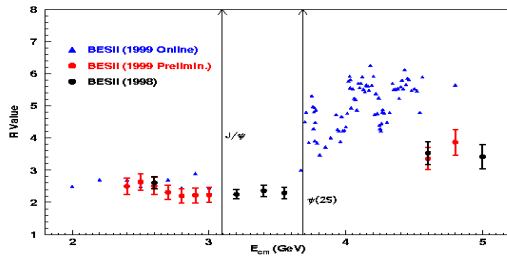


Figure 5:  $R$ -measurement in the BEPC/BES

As a synchrotron radiation light source, the BEPC has provided beams for users in both parasitic and dedicated ways. About 1/4 of beam time of the BEPC is devoted to the dedicated SR operation. Figure 6 shows the beam currents vs. time in a day.

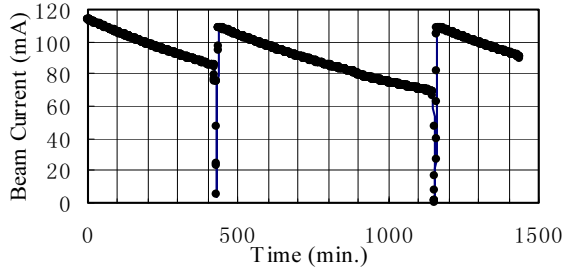


Figure 6: Beam currents vs. time for SR operation

The user number of BSRF has steadily increased since 1989. About 450 users came to IHEP to carry on their researches in the past year. The research fields are shown in Figure 7.

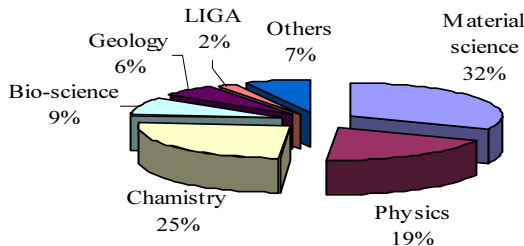


Figure 7: The research fields of BSRF users

It is noted that such a significant field as bioscience has only taken 7% of SR beam time. With growing demands of synchrotron radiation users, tow insertion devices and their successive beamlines and experimental stations will be constructed in BSRF. Figure 8 displays the in-vacuum permanent wiggler to be installed in the BEPC storage ring next summer.

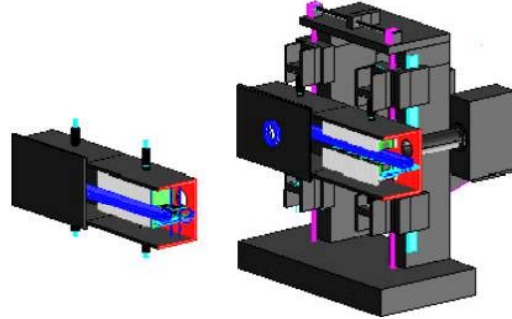


Figure 8: The in-vacuum wiggler in the BEPC

## 2 THE PLAN OF BEPCII

The physics opportunity in the charm- region calls higher luminosity. The BEPCII, with a luminosity goal of two orders of magnitude higher than the present BEPC, called BEPCI, is its natural extension [4].

### 2.1 Luminosity from BEPCI to BEPCII

As a measure of the event production rate, luminosity is one of the most important parameters in colliders. 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.

With the parameters given in Table 1 of  $E = 1.55$  GeV,  $\xi_y = 0.04$ ,  $\beta_y^* = 5$  cm,  $k_b = 1$  and  $I_b = 22$  mA, assuming  $R = \sigma_y^* / \sigma_x^* \approx \beta_y^* / \beta_x^* = 0.042$ , the luminosity of the BEPCI is calculated from eq. (1) as  $0.62 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$ , which is in a good agreement with the measured value of  $0.5 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$  at 1.55 GeV. Table 2 describes the strategy of the luminosity upgrading from the BEPCI to the BEPCII.

Table 2: The luminosity strategy from BEPCI to BEPCII

Parameters	BEPCI	BEPCII
Beta function at IP $\beta_y^*$ (cm)	5.0	1.5
Bunch number $k_b$	1	93
Beam-beam parameter $\xi_y$	0.04	0.04
Current per bunch $I_b$ (mA)	22	12
Luminosity gain $L_{BEPCII} / L_{BEPCI}$	1	169

## 2.2 Main Parameters

Based on the strategy of the luminosity upgrading of the BEPC, the design study for the BEPCII is worked out. Table 3 summarises the main parameters of the BEPCII in comparison with the BEPCI.

Table 3: The main parameters of the BEPCII

Beam Energy $E$	GeV	1.55 (1.89)
Circumference $C$	m	237.53
Bunch Number $k_b$		93
Beam Currents per Ring $I_{beam}$	mA	1116
RF Frequency $f_{RF}$	MHz	499.8
RF Voltage per ring $V_{RF}$	MV	1.5
Beta Function at IP $\beta_x^*/\beta_y^*$	cm	100/1.5
Emittance $\epsilon_x/\epsilon_y$	m-mr	0.21/0.00315
Bunch Length $\sigma_{z0}/\sigma_z$	cm	1.1/1.5
Bunch Spacing $S_b$	m	2.4
Impedance $ Z/n _0$	$\Omega$	< 0.7
Tune $\nu_x/\nu_y/\nu_z$		6.58/7.64/0.47
Damping Time $\tau_x/\tau_y/\tau_z$	ms	44/44/22
Beam-beam Parameter $\xi_x/\xi_y$		0.04/0.04
Crossing Angle $\phi_c$	mrad	11 $\times$ 2
Luminosity $L$	$\text{cm}^{-2}\text{s}^{-1}$	1 $\times$ 10 <sup>33</sup>

## 2.3 The Double-ring Structure

Figure 9 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 SC magnets serves this purpose in the southern IR, so that electron beams can be circulated in the outer ring for the dedicated synchrotron radiation runs of the BEPCII. The design beam currents for synchrotron radiation are 250 mA at 2.5 GeV and 150 mA at 2.8 GeV respectively.

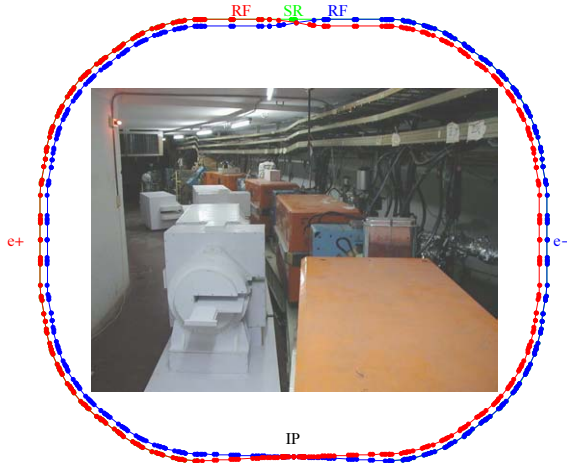


Figure 9: The layout of the double ring of the BEPCII

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 3. However, the space for the two rings in the existing BEPC tunnel needs to be carefully checked. The wood model test (see the photo in Figure 9) was carried out to examine the feasibility of the double ring installation. The conclusion is as follows.

- No unsolvable 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 crucial issues for the success of the micro- $\beta$  scheme in the BEPCII. There are experimental and theoretical evidences that the bunch length in a collider should be smaller or comparable to the  $\beta$ -function at IP. The bunch length in the BEPCI is about 5 cm in the operation condition of  $I_b \sim 20$  mA,  $V_{rf} \sim 0.6$  MV at 1.55 GeV. In order to operate the collider with micro- $\beta$  scheme of  $\beta_y^* = 1.5$  cm, the bunch length  $\sigma_l$  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  $\sigma_{l0} = 1.1$  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 increase due to potential well distortion and microwave instability. The threshold of microwave instability is

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

where  $\alpha_p$  is the momentum compaction factor,  $E$  the energy of the beam,  $\sigma_{e0}$  and  $\sigma_{l0}$  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  $0.7\Omega$  for the design current of 12 mA.

In order to make the impedance  $|Z/n|_{eff}$  smaller than  $0.7\Omega$ , 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. Table 4 lists the impedance budget of the BEPCII.

Table 4: Impedance budget of the BEPCII

Component	$N$	$L$ (nH)	$k_L$ (V/pC)	$P_{HOM}$ (kW)
RF cavity	1	1	~0.50	5.3
Resistance Wall			0.18	1.9
BPMs	72	2.6	0.15	1.6
Bellows	67	0.46	0.01	0.1
Mask	70	4.9	0.14	1.4
Pumping Ports	DIP	0.1		
	LP	0.1		
Taper	4	1.2	0.05	0.5
Injection port	1	0.17	0.005	0.1
Kicker	2	0.003	0.06	0.6
Y-shape structure	4	2.24	1.92	19.2
IR	1	3.8	0.03	0.3
Collimator	2	2.54	0.03	0.3
Total		19.1	3.1	31.0

According to the above impedance budget, the total inductance of BEPCII is about 19.1 nH, corresponding to  $Z/n \sim 0.16\Omega$ . The table 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 dangerous modes of the coupled bunch instability with  $N_b=99$ ,  $I_b=12$  mA are  $\tau_{rise}=2.2$  ms (longitudinal  $m=0$ ) and  $\tau_{rise}=16.5$  ms (transverse  $m=1$ ), which are shorter than the SR damping time of the BEPCII at 1.55 GeV of ( $\tau_x/\tau_y/\tau_z=44/44/22$  ms). 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. A bunch feedback system can be applied to cure the instability.

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 16.4 ms with  $N_b=99$ ,  $I_b=12$  mA at the present design tunes. It can easily be handled with a feedback system.

The electron and positron beams will circulate with the separated rings in the BEPCII, we have concerned the foreign particle caused instabilities such as ion trapping, fast ion instability, dust effect and electron cloud

instability. 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  $\pm 11$  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  $\langle L \rangle_{max} = 0.5 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ .

### 2.5 Key Technologies and Hardware

Number of key technologies and hardware systems need to be developed for the BEPCII, including injector upgrading, superconducting RF system, superconducting insertion quadrupoles and IR design, low impedance vacuum system and some others.

The BEPCII requires the injector in two aspects. One is the full energy injection to the storage ring, i.e.  $E_{inj} = 1.55-1.89$  GeV, the other is that the positron intensity satisfies the required injection rate of 50 mA/min. In order to realize the full energy injection for  $E = 1.55-1.89$  GeV, present-used 34 MW klystrons will be replaced with the new 50 MW devices.

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 have been compared for the BEPCII. The later is considered to be the first choice 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  $2 \times 1.5$  MV RF voltage. The cavities will be powered with two 180 kW RF transmitters. The refrigeration capability of 300W is required for two SC cavities at the RF voltage of 1.5MV/cavity. Considering a sufficient margin, the refrigerator of 500-600W will be chosen in the BEPCII

One pair of quadrupoles will be inserted in the BES detector to squeeze the  $\beta$  function at IP. For the tight space in the interaction region, two types of insertion quadrupoles are considered, one is the permanent

magnets and other the superconducting magnets. The permanent magnets are compact and no power supply required. However, it is difficult to satisfy the wide operation range of the beam energy in the BEPCII using this type of magnets. The superconducting magnets can provide a strong and adjustable magnetic field. A special pair of superconducting IR magnets is being designed with main and skew quadrupole and dipole coils. Figure 8 shows its profile.

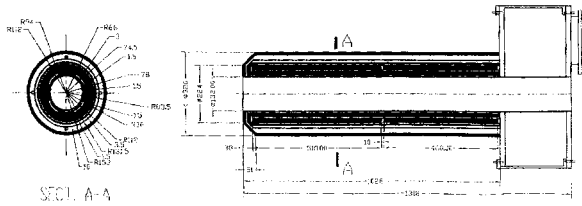


Figure 8: The superconducting IR magnet

The support, installation, background shielding, vacuum pumping and many other issues in the IR are being carefully studied. Figure 9 shows the sketch of the IR.

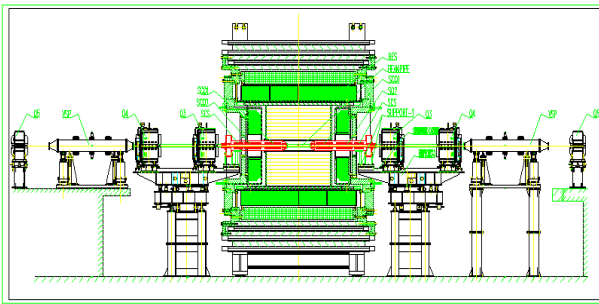


Figure 9: The sketch of the interaction region

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, as well as the background in the detector. The design vacuum pressure of the BEPCII is  $5 \times 10^{-9}$  Torr in the arc and  $5 \times 10^{-10}$  Torr in the IR. The heating due to the synchrotron radiation needs to be checked. To reduce the impedance, the vacuum chamber should be as smooth as possible. Some of the chamber structures will be shielded; some will be replaced with new-designed components.

The upgrades also involve injection, magnets and their power supplies, instrumentation, control and others. A new ring will be built in the same tunnel.

The BEPCII project is approved in principle, while the final approval is expected only when the detail design is reviewed. The project is scheduled to be completed in 3-4 years after the final approval.

### 3 INTERNATIONAL COLLABORATION

As discussed in the previous sections that the near future development of IHEP is upgrading of the BEPC and BES with the main physics windows in charm

and  $\tau$  energy region. In the meantime, non-accelerator physics experiments, the neutrino experiments, astrophysics and cosmic ray physics are also emphasised.

The international collaboration on the BEPCII will be promoted. The collaborative items include: impedance study, machine experiment on electron cloud instability, linac upgrade, SC RF cavities, SC micro- $\beta$  quadrupoles, beam instrumentation and others.

It is realized that next generation accelerators, such as LHC and VLHC, linear colliders, neutrino factories,  $\mu^+ - \mu^-$  colliders, and other exotic accelerators, are going to be international facilities. There are good chances and big challenges. IHEP will make every effort to contribute to the collaboration.

Just as an example, the long-baseline neutrino oscillation experiment from JHF to Beijing is being discussed. The energetic proton beams from JHF interact with the target and producing intense neutrino beams. The distance from JHF to Beijing of 2200 km is ideal for measurement of neutrino CP violation phase and many other interesting physics. There is a good tunnel available 20 km north of Beijing, near highway to the Great Wall. KEK and IHEP are working together at the joint study about its physics and required facility. The Monte Carlo simulation for the neutrino propagation is carrying out, the requirement to beam lines is investigated, and the detector concept design is underway.

### 4 SUMMARY

- The BEPC has been well operated with many exciting HEP and SR results for 12 years since it was put into operation in 1989.
- The BEPCII is proposed as micro- $\beta$  plus multi-bunches with design luminosity of two orders of magnitude higher than the present BEPC in the energy range of  $J/\psi$  and  $\psi'$ . Some key technologies need to be developed in order to achieve the goal of the BEPCII.
- For the future development of high energy physics and high-energy accelerators, we are ready to join international collaborations in a variety of ways.

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