BEPC II: construction and commissioning*

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Abstract This is a status report of the project on befalf of the BEPC II team. BEPC II is a major upgrade of the BEPC (Beijing Electron-Positron Collider). It is a double-ring e^+-e^- collider as well as a synchrotron radiation (SR) source with its outer ring, or SR ring. As a collider, BEPC II operates in the beam energy region of 1—2.3 GeV with design luminosity of 1×10^{33} cm^{-2}s^{-1} at 1.89 GeV. As a light source, the SR ring operates at 2.5 GeV and 250 mA. Construction of the project started in the beginning of 2004. Installation of the storage ring components was completed in October 2007. Commissioning is in progress. There are still many issues for further studies before reach to 3×10^{32} cm^{-2}s^{-1}.

Key words collider, synchrotron radiation, luminosity, construction, commissioning

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1 Introduction

BEPC II serves the purposes of both high energy physics experiments and synchrotron radiation applications. Details of the BEPC II design can be found in its design report[1]. The design goals of BEPC II are shown in Table 1.

Table 1. Design goals of BEPC II.

beam energy	1—2.3 GeV
optimum energy	1.89 GeV
luminosity	1×10^{33} cm^{-2}s^{-1}@189 GeV
linac injector	full energy inj.: 1.55—1.89 GeV
	positron inj. rate ⩾50 mA/min
dedicated SR	250 mA@2.5 GeV

Serving as a collider, BEPC II will operate in the beam energy region of 1.0—2.3 GeV so that its physical potential in τ-charm range is preserved. The design of BEPC II aims at a high luminosity. Luminosity of an e^+-e^-collider is expressed as

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

where $r=\sigma_y^*/\sigma_x^*$ is the beam aspect ratio at interaction point (IP), ξ_y is the vertical beam-beam parameter, β_y^* is the vertical β-function at IP, k_b is the bunch number in each beam and I_b is the bunch current. The strategy for BEPC II to reach the design luminosity is to apply multi-bunch collisions (k_b=93) with double rings and micro-β at IP with short bunches whose length is compatible with the β_y^* value. The layout and installed double-ring accelerator units in the BEPC II tunnel are shown in Fig. 1.

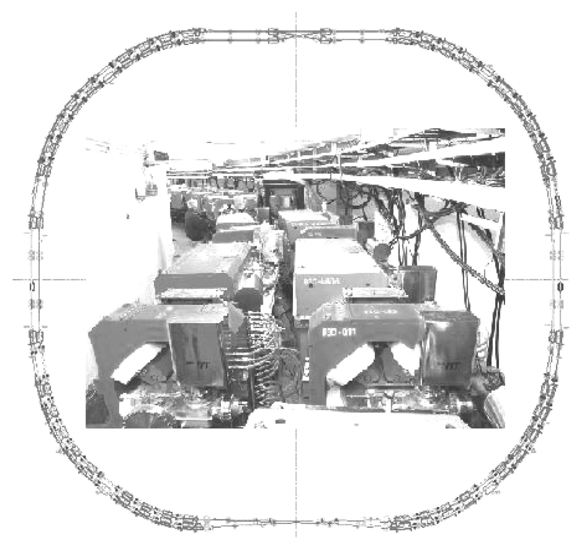

Fig. 1. Layout and installed double-ring units.

The inner ring and the outer ring cross each other in the northern and southern IPs. The horizontal

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crossing angle between two beams at the southern IP, where the detector locates, is 2×11 mrad to meet the requirement of sufficient separation but no significant degradation to luminosity. While in the northern crossing region, two beams cross horizontally and a vertical bump is used to separate two beams, the optics of two rings is symmetric. For the dedicated SR operation, electron beams circulate in the outer ring with a pair of horizontal bending coils in the supercunducting magnets and in the northern crossing a bypass is designed to connect two halves of the outer ring. Detailed machine physics issues on the storage rings are discussed in Ref. [2].

Milestones of BEPCII are as follows:

January 2004	Construction started
May. 4, 2004	Dismounting of linac sections started
Dec. 1, 2004	Linac delivered e^- beams for ring
July 4, 2005	BEPC ring dismounting started
Mar. 2, 2006	BEPCII ring installation started
Nov. 13, 2006	Phase 1 commissioning with conventional IR magnets started
Dec. 25, 2007	Phase 2 commissioning with SC IR magnets started
Jan. 29, 2008	2×500 mA e^+e^- collision with luminosity $>1\times10^{32}cm^{-2}s^{-1}$
June 22, 2008	Phase 3 commissioning with BESIII detector started

2 Injector linac

The BEPC injector is a 202-meter e^--e^+ linac with 16 RF power sources and 56 S-band RF structures. BEPCII requires the injector in two aspects. One is the full energy of e^- and e^+ beams injected into the storage rings, i.e. $E_{inj} \geqslant 1.89$ GeV; the other one is e^+ injection rate ⩾50 mA/min. To realize the full energy top-off injection up to 1.89 GeV, the klystrons are replaced with new 45—50 MW ones and the modulators upgraded with new pulse transformer oil tank assembly, PFN's, thyratrons, charging choke and DC power supplies. In order to compensate for the RF phase drift due to various factors, an RF phasing system was developed.

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

All the new hardware subsystems, including the electron gun, the 40 MeV pre-injector, the 200 MeV booster section and the positron source of the linac were installed in the summer of 2004 after dismounting the old devices. Fig. 2 shows the BEPCII linac injector.

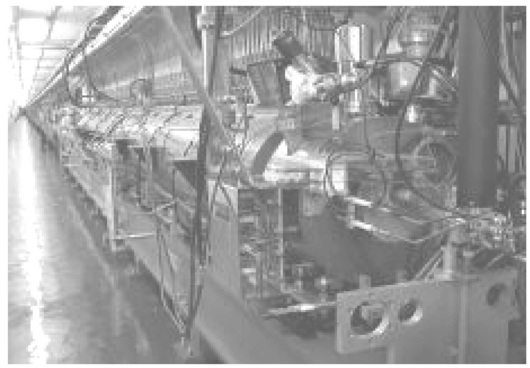

Fig. 2. The BEPCII linac injector.

It took less than one month to start up the machine and process the new systems before the linac provided electron beams for the dedicated SR operation of the BEPC storage ring starting from the beginning of December 2004. The commissioning of the linac for e^+ beam was carried out during machine studies. The first e^+ beam of 50 mA was obtained at the linac end on March 19, 2005. The e^- beam current output from the gun is about 10 A, and 6 A at the positron converter target which agrees with simulation. All of the 16 RF power sources were rebuilt, and stably operated at 50 Hz. The new control and beam instrumentation systems make the machine commissioning and operation more convenient. The performance of the linac is listed in Table 2, showing that its design specification is reached.

Table 2. The results of the linac commissioning.

	unit		measured	design
energy	GeV		1.89	1.89
beam current	mA	e^+	66	40
		e^-	550	500
emittance	mm·mr	e^+	0.31	0.4
		e^-	0.088	0.1
energy spread	%	e^+	0.37	0.5
		e^-	0.30	0.5
repetition rate	Hz		50	50
pulse length	ns		1.0	1.0
e^+injection rate	mA/min.		62	50

3 The storage rings

The BEPCⅡ storage rings consist of three rings, i.e. the e^- ring (BER), the e^+(BPR) ring and the SR ring (BSR). The e^- and e^+ rings are identical, while the SR ring takes two outer halves of the e^- and e^+ rings. Table 3 lists the main parameters of the BEPCⅡ storage rings.

Table 3. Main Parameters of the BEPCⅡ storage rings.

parameters	unit	collision	SR
energy	GeV	1.89	2.5
circumference	m	237.53	241.13
RF frequency	MHz	499.8	499.8
RF voltage	MV	1.5	1.5∼3
beam emittance	nm·rad	144	120
bunch number		93	200-300
beam current per ring	A	0.91	0.25
injection energy	GeV	1.89	1.89
β function at IP	m	1/0.015	-
crossing angle	mrad	11× 2	-
beam-beam param.		0.04	-
luminosity	$cm^{-2}\cdot s^{-1}$	1×10^{33}	-

3.1 RF system

Two superconducting cavities are installed in BEPCⅡ with one cavity in each ring providing RF voltage of 1.5 MV. Each cavity is powered with a 250 kW klystron. High power test gives the Q values of 5.4×10^8 and 9.6×10^8 at $V_{rf} = 2$ MV for the west and east cavities, higher than the design values of 5×10^8 at 2 MV. Fig. 3 pictures the cavity under installation.

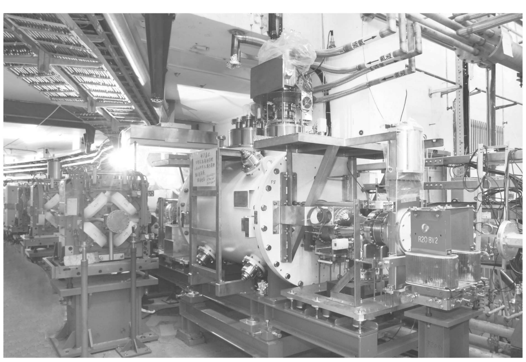

Fig. 3. A superconducting cavity in installation.

3.2 Magnets and power supplies

BEPCⅡ reuses 44 BEPC bends and 28 quads. There are 267 new magnets, including 48 bends, 89 quads, 72 sextupoles, 4 skew quads and 54 dipole correctors, which need to be produced. Most magnets were fabricated at the IHEP workshop. The magnets were measured with both rotating coils and straight wires. The results are in agreement each other within 10^{-3}. There are 1 electric and 3 permanent wigglers in the storage rings serving as SR wavelength shifters. Among the 3 permanent wigglers, two are out-vacuum and one is in-vacuum.

To provide required flexibility for BEPCⅡ operation with various modes, each arc quadruple is excited with an independent power supply. There are all together 345 power supplies in the storage rings. Their current stability of the power supplies is better than 1×10^{-4}.

3.3 Vacuum system

BEPCⅡ poses two challenges to the vacuum system, one is the vacuum pressure, and the other one is the impedance. The design dynamic vacuum pressures are 8×10^{-9} Torr in the arc and 5×10^{-10} Torr in the IR. Antechambers are chosen for both the e^+ and e^- rings. For the e^+ ring, the inner surface of the beam pipe in the arc is coated with TiN in order to reduce the secondary electron yield (SEY). Measurement results show that the maximum SEY is 1.6—1.9 after the coating, much smaller then the SEY of aluminium, seen in Fig. 4.

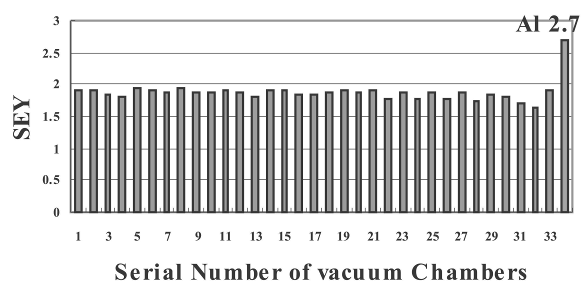

Fig. 4. Measured SEY of TiN-coated chambers.

3.4 IR and SC insertion magnets

The IR has to accommodate competing and conflicting requirements from the accelerator and the detector. Many types of equipment including magnets, beam diagnostic instruments, masks, vacuum pumps, and BESIII detector must co-exist in a crowded space. A special pair of superconducting insertion magnets (SIM's) is placed in the IR. Each SIM consists of a main quadrupole, a skew quadrupole, 3 compensation solenoids and a dipole coil, to squeeze the β function at the IP, compensating the detector solenoid and to serve as the bridge connecting outer ring for SR operation, respectively. The SIMs were installed into the

IR in Oct. 2007. Some special warm magnets in the IR such as septum bending magnets and two-in-one quadrupoles were manufactured, tested and installed. Fig. 5 shows two SCMs and some warm magnets installed in the IR.

Fig. 5. Two SIMs and some warm magnets in IR.

3.5 Instrumentation and control

The instrumentation system consists of 136 beam position monitors (BPM's), 2 DCCTs, 2 bunch current monitors and 2 synchrotron radiation monitors. Transverse feedback systems are equipped in order to damp beam instabilities[3]. The control system is based on the EPICS environment, providing a friendly man-machine interface for operators. The instrumentation and control systems have been examined during the commissioning.

3.6 Cryogenics system

The BEPC II cryogenics system is composed of four sub-systems: the central cryogenic plant and three satellite cryogenic systems for the RF cavities, the SIM magnets, and the detector superconducting solenoid magnet (SSM). Two 500 W refrigerators serve to cool the superconducting devices at 4.5 K, one for the cavities and the other one is for the magnets. The cryogenic system has been in operation since the problem of the control Dewar, valve boxes and current leads for SIMs was solved in May 2007.

4 Commissioning

The operation of BEPC was completed on July 4, 2005, and then dismounting of the old ring started. The storage ring installation was completed in early November 2006 except the cryogenics of the magnets. It was decided to install conventional magnets in the IR to start storage ring commissioning and SR operation. In the meantime, the improvement of the cryogenics system and measurement of the SC magnets were carried out at the BESIII off-line position.

The commissioning of BEPC II involves three rings: the BER, the BPR and the BSR. The Phase 1 commissioning started on Nov. 13, 2006 with warm magnets in the IR. The beam current in collision got above 100 mA with the luminosity higher than that in BEPC[4] in this phase of commissioning.

The Phase 2 commissioning with SIMs in the IR started on Oct. 24, 2007. By the end of January 2008, 2×500 mA e^--e^+ beam collision was realized, and the luminosity measured with zero-degree γ detector was higher than $1\times10^{32}\text{cm}^{-2}\cdot\text{s}^{-1}$. The beam current in the BSR reached its design value of 250 mA with full energy injection from the linac[4]. The performance with high current and luminosity was realized by Twiss parameter corrected, orbit correction, vacuum cleaning with large beam dose, RF conditioning, bunch-by-bunch feedback, cooling in beam dusts, beam-beam tune scan, collision optimization, single bunch collision optimization, more bunch collision, and sophisticated machine studies. The details are presented in Ref. [5]. Fig. 6 displays growths of the beam current in the BER and the BPR. Collision of e^+-e^- beams is realized with beam-beam scan when the beam orbit of e^- or e^+ at IP is scanned measuring orbit changes due to beam-beam interaction, shown in Fig. 7.

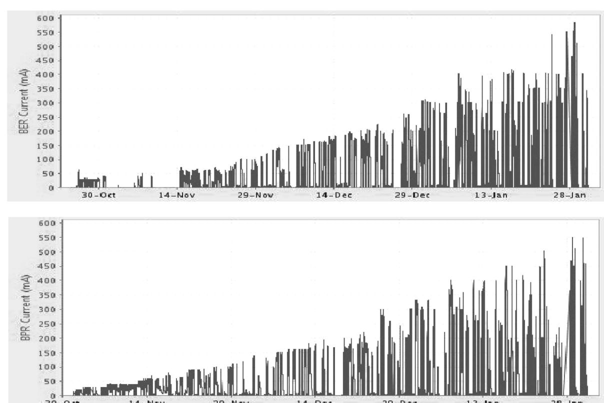

Fig. 6. Current growth in BER (upper) and BPR (down) during Phase 2 commissioning.

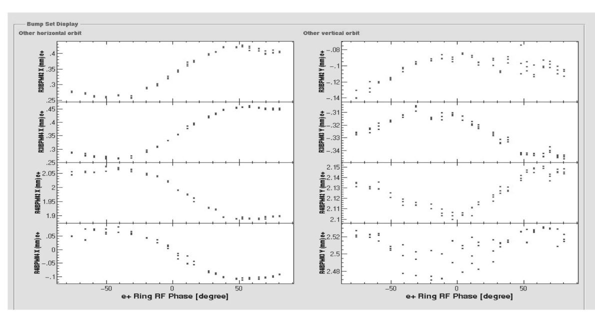

Fig. 7. Plot of beam-beam scans.

The BESIII detector was moved into the BEPC II interaction region in mid-April, 2008. Fig. 8 pictures the BESIII detector together with the IR magnets of BEPCII. The collider has beam operated together with BESIII detector i.e. Phase 3 commissioning since June 22, 2008 after the IR had been reinstalled.

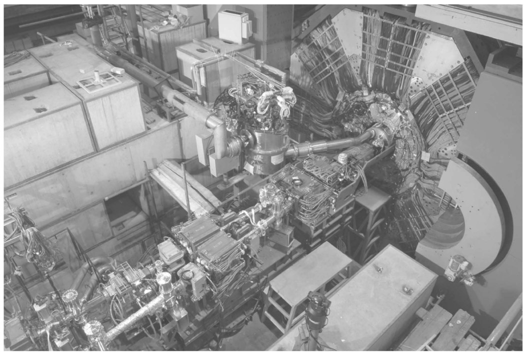

Fig. 8. The IR with the BESIII detector.

The SSM solenoid field of 1Tesla will generate strong transverse coupling and perturb e^- and e^+ beams and their collision. Three sets of anti-solenoid coils, i.e. AS1, AS2 and AS3, are equipped in each of the two SIMs. Fig. 9 displays joint field mapping of the SSM and SIM anti-solenoid. The anti-solenoid compensation works perfectly and coupling of both rings is measured as less than 0.5%. Issues on noise and background in the BESIII detector have been intensively studied with their reduction step-by-step.

The commissioning is in progress. There are still many issues for further studies before reach 3×10^{32} $cm^{-2}\cdot s^{-1}$.

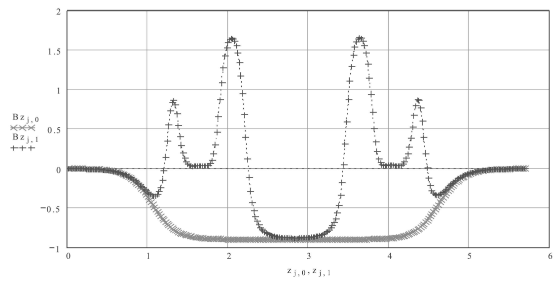

Fig. 9. Field mapping of the SSM (red) and AS1, AS2 and AS3 (blue).

References

1 BEPCII Group. BEPCII Design Report. IHEP-Proc., Aug. 2001
2 XU G et al. HEP & NP, 2006, **30**(S1): 60—62 (in Chiness)
3 YUE J H et al. HPL & PB, 2004, **16**(10): 1353—1355
4 WANG J Q et al. Proc. EPAC'08, Italy, July. 2007
5 QIN Q et al. these Proceedings, August 2008