BEPC AND THE FUTURE PROGRAM AT IHEP

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Abstract

Beijing Electron and Positron Collider (BEPC), a 1.55—2.8GeV accelerator facility serving for both high energy physics experiment and synchrotron radiation application, was constructed in the years from 1984 to 1988. The BEPC has been operating since 1989, in the meantime the BEPC upgrades were conducted and Beijing Tau-Charm Factory, a 1.5—2.5GeV double-ring collider was designed in the period from 1993 to 1996. In this paper, the BEPC and its current status are briefly introduced, the recent progress and the achieved results of the BEPC upgrade project are presented, and the future program of BTCF/BEPC-II is described.

1 INTRODUCTION

Beijing Electron and Positron Collider (BEPC) is the first high energy accelerator facility ever built in China[1]. It consists of four main parts, a 200m-long Linac injector providing electron and positron beams of 1.1—1.55GeV, a storage ring in a race track shape and with a circumference of 240m accumulating and accelerating electrons and positrons to 2.2—2.8GeV, a general-purpose magnetic spectrometer located in the south interaction region, and the synchrotron radiation facility (BSRF) around the south part of the storage ring.

The construction of BEPC began in October 1984, and the electron and positron collision was first realized in October 1988. The Beijing spectrometer (BES) was moved into the interaction region in May 1989. Since then the BEPC has been operating for high energy physics experiments as a collider and for synchrotron radiation applications in parasitic and dedicated modes as a light source. The BEPC layout and machine configuration and parameters were reported in details elsewhere[2][3][4].

The BEPC upgrades project was performed in the passed few years[5][6], aiming at higher luminosity for high energy physics experiment and higher brightness for synchrotron radiation applications. This project was approved by Chinese Academy of Sciences in May 1993, the upgrading works of hardware systems were completed before 1996, and the collider luminosity gain by a factor of 1.5 at J/Ψ energy was achieved in May 1996 through a preliminary commissioning about two months. The newly developed multi-period permanent magnet wiggler (3W1) was installed into the storage ring in June of 1996, and then the photon brightness about 10 times higher than that from the existed beam line was provided by the newly constructed beam line 3W1A in May 1997.

The rich physics in Tau-Charm energy region encourages the Chinese high energy physics community to design and construct a new Tau-Charm physics advanced research facility, Beijing Tau-Charm Factory (BTCF) and the further upgrading BEPC with multi-bunch pretzel scheme (BEPC-II) are proposed to be the candidates of the future program at IHEP. The feasibility study of BTCF was supported by Chinese government in February 1995, and successfully performed in the following one and half year[7]. It was positively reviewed by an international review panel in November 1996. The proposal on BEPC-II was discussed as early in 1991[8], and a preliminary design was carried out in the last few years[9]. The studies on both BTCF and BEPC-II are all going on at IHEP now, the R&D of the key issues concerned BTCF and BEPC-II is expected to be approved in the coming years.

2 BEPC OPERATION STATUS

BEPC has been well operating since May 1989, some important physics results, such as precise Tau-mass measurement, and a lot of synchrotron radiation research achievements have been obtained, which makes an efficient “dual uses in one machine”. Even in the BEPC upgrades period from 1993 to 1995, while hardware systems upgrades were being made in progress, the BEPC was still kept in operation.

The running time of BEPC was about 5500-6000 hours each year and the operation efficiency was above 90%. Table.1 shows the main operation parameters and collected events or integrated luminosity before 1996. The running time was shared by high energy experiments, synchrotron radiation applications and machine studies.

Table 1. Operation parameters and collected data

	J/Ψ	$\tau^+\tau^-$	Ψ′	Ds(Do)
Energy(GeV)	2×1.548	2×1.777	2×1.834	2×2.015
Current(mA)	20×2	25×2	27×2	30×2
Luminosity ($10^{30}cm^{-2}s^{-1}$)	3-4	4-5	5-6	5-7
Total Events or Int. Luminosity	9×10^6	$4.7pb^{-1}$	5.8×10^6	$23.5pb^{-1}$

With the consistent and tremendous efforts in the machine component improvements and machine studies, the integrated luminosity was increased year by year. Figure 1 shows that the integrated luminosity per day at Ds energy (2.015GeV per beam) grew up by a factor of 1.65 from 1992 to 1994. Figure 2 shows that the integrated luminosity per day at Ψ′energy (1.845GeV per beam) was increased by a factor of 1.22 from 1994 to 1995. In the BEPC run of 1996/1997, the preliminary machine commissioning for R-Scan physics experiment was performed, and the electron and positron collision was realized at 9 different kinds of center mass energy from 2.0GeV to 5.0GeV.

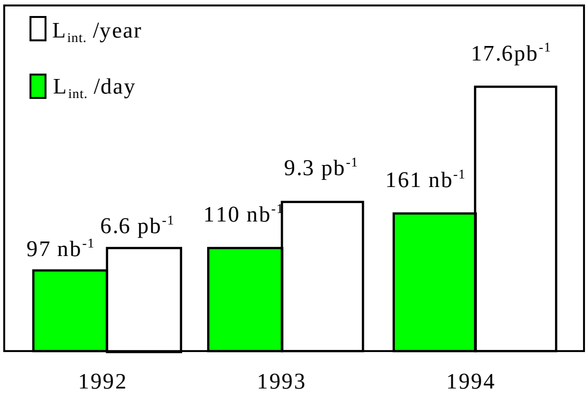

Figure 1. Integrated luminosity at Ds energy

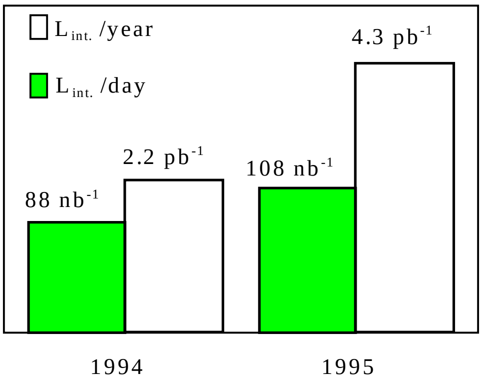

Figure 2. Integrated luminosity atΨ' energy

3 BEPC UPGRADES STATUS

3.1 BEPC Luminosity Upgrades

In the initial plan, the mini-β optics and single interaction point collision as well as the beam emittance control were the main measures considered for BEPC luminosity upgrades[5]. The mini-β optics was believed to be the most effective way to upgrade the machine luminosity. Under this consideration, the vertical beta function at the interaction point, β^*_y, was designed to be decreased from 8.5cm to 3.6cm, and the peak luminosity enhanced factor was expected to be 2.4 if the bunch length could be shrunk to 3cm at 2.015GeV and 35mA. In order to shorten the bunch length, the total RF voltage was increased from 0.8MeV to 2.0MeV by adding two SPS cavities and regrouping the existing high power RF amplifiers. The ring impedance was reduced by taking two kicker magnets out of the storage ring and by shielding the 66 small cavities formed by bellow flanges of the ring vacuum chamber. However the bunch lengthening effect is still out of control, the shortest bunch length available in BEPC at 2.015Gev and 35mA is 4.2cm. For understanding this phenomenon the bunch length versus different energy and beam current as well as RF voltage were precisely measured by using streak camera, which was described as a scaling law.[10]

From the above shortest bunch length in the existing BEPC storage ring, the minimum β^*_y is determined to be about 5cm. Instead of adding the mini-β permanent quadruple magnets into the detector region, the insertion quads of Q1 and Q2 were moved towards the interaction point by 35cm and 45cm respectively. Correspondingly the β^*_y was reduced from 8.5cm to 5cm. After a preliminary machine commissioning about two months, the peak luminosity at J/Ψ energy reached 4.38×10^{30} $cm^{-2}s^{-1}$ in May 1996. As shown in Figure 3, the luminosity gain factor is about 1.5. The machine commissioning for luminosity gain at Ds energy was scheduled this year.

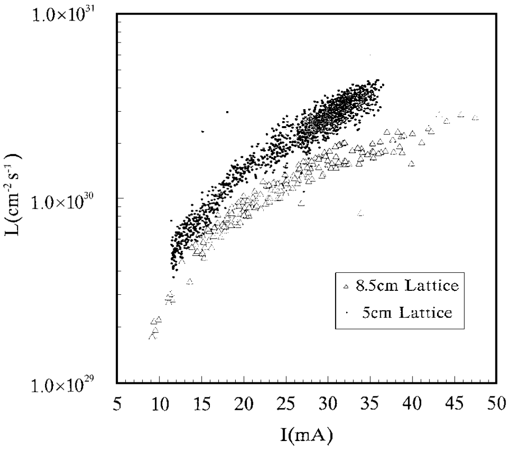

Figure 3. Luminosity versus total beam current

3.2 Linac Energy Upgrade

In the test run of May 1996, the Linac energy of BEPC was increased from 1.3GeV to 1.55GeV which met the requirement of the full energy injection to the storage ring for J/Ψ physics experiment[11]. This energy gain was obtained by using two sets of newly developed 65MW klystron and its 150MW modulator, and by stretching the microwave pulse from 3.2μs to 3.7μs to get more peak power from the Energy Doubler.

3.3 Control System and Beam Instrumentation Upgrades

The BEPC central control system and the Linac local control system as well as the safety interlock system were all upgraded or reconstructed[12][13][14]. The architecture of the central control system was transformed from a centralized system to a distributed one based on Ethernet, which made the system faster in response and more reliable in performance. All these control system upgrades profited the stable operation of the BEPC Linac and storage ring in recent runs.

The beam diagnostic system, including the tune, bunch length and transverse beam size measurements, the beam position monitor, was well upgraded both in its measurement precision and in its speed[12], as shown in Table 2. The computerization and automation of the beam measurement were also realized by reconstructing the data acquisition setups.

Table 2. Improvements of Beam Monitor System

Measurement	Resolution		Speed	
Upgrade	Before	After	Before	After
BPM(σ_{ave})	>50μm	<10μm	50s	15s
Tune($\Delta\nu/\nu$)	10^{-3}	10^{-4}	>10s	2s
Cross section ($\Delta\sigma/\sigma$)	10%	1%	>30s	<2s

3.4 *BES Upgrades*

The BES was reconstructed during the BEPC upgrading period for getting lower background and faster acquisition rate of events. The test run showed that the time of flight counter (TOF), the Vertex chamber, the related electronics system, the on-line and off-line data acquisition were well improved in their performance. However the main drift chamber (MDC-II) failed to be in normal operation due to the discharge problem of its feedthrough for wires. To solve this problem, the MDC-II was modified by applying the hybrid voltage to wires. The concerning test run was scheduled in the coming April.

The hadron events rate at J/Ψ energy detected by the upgraded BES (BES-II) was doubled after BEPC upgrades, in which about 70% was attributed to the collider luminosity upgrade, and 30% came from the improvement of the detector acquisition rate.

3.5 *BSRF Upgrade*

As part of BEPC upgrades project, BSRF upgrade was carried out in the last few years. The existing 7 beam lines and the corresponding 11 experiment stations were improved to enhance the BSRF ability for conducting high quality research experiments. A permanent magnet wiggler(3W1) was successfully developed and installed into storage ring to replace the existing electromagnet wiggler in June 1996. This wiggler has 5 magnet periods and field strength of 1.5Tesla, its gap can be changed from 220mm to 43mm during the operation. Its equipping beam lines 3W1A and 3W1B for hard and soft X-ray were constructed in the meantime, and the photon brightness provided by 3W1A in last run reached one order higher than that from the existing beam line.

4 THE FUTURE PROGRAM

The BEPC achievements and the rich physics in Tau-Charm energy region encourage Chinese scientists to pursue a new Tau-Charm physics advanced research facility, either BTCF or BEPC-II. Its energy range of single beam is 1.5 to 2.5GeV, and the collider luminosity expected is $10^{32} \sim 10^{33}$ cm^{-2}s^{-1}at 2.0GeV. BTCF is a nature extension of BEPC, with which some potential discoveries in physics could possibly be made by using its higher intensity and polarization colliding beams, BEPC-II with luminosity of 10^{32}cm^{-2}s^{-1} at 2.0GeV is another possible way to continuously develop high energy experiment physics in China, some important physics such as glue ball could be well studied by this upgraded machine. The final choice of the future project at IHEP will be made after the R&D concerning the common key issues both in BTCF and BEPC-II in few years.

4.1 *BTCF*

The feasibility study on BTCF was initiated in the beginning of 1995 and reviewed by end of 1996. As a result of this study, a reference design[7] on BTCF was completed and published with a preliminary BTCF facility layout as shown figure 4. Moreover the concerning studies continued going on, and the lattice design and interaction region design as well as polarization scheme study achieved satisfactory progress last year[15][16] [17][18].

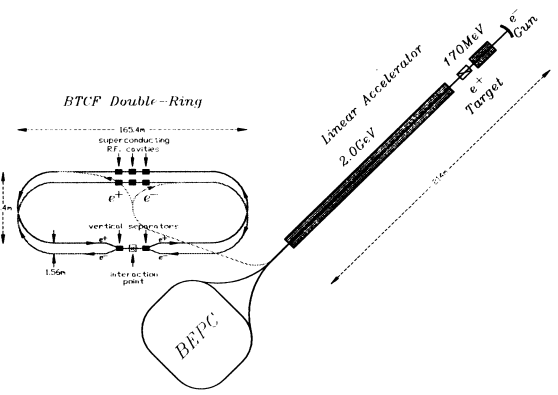

Figure 4. BTCF facility layout

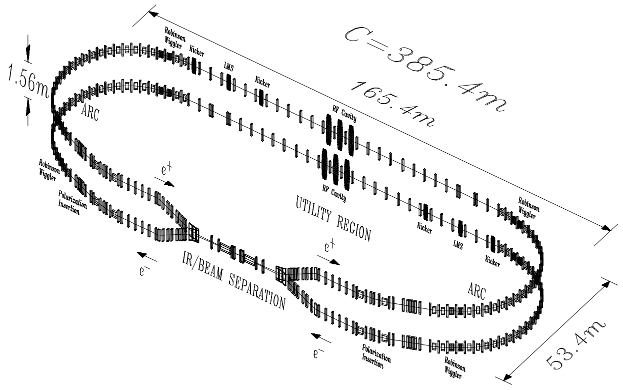

Figure 5. BTCF storage rings

BTCF is a double-ring collider with one interaction point, as shown in Figure 5. The two rings are vertically separated about 1.6m, each ring is 53m wide and l65m long with a circumference of 385.4m. The ring can be divided into four kinds of regions: the interaction region, two polarization insertion regions, two arc regions and a utility region with injection and RF sections.

The BTCF design goals are: (1) the maximum peak luminosity of 10^{33} cm^{-2}s^{-1} at energy of 2.0GeV, (2) the operating energy from 1.5GeV to 2.5GeV with the potential up to 3.0GeV, (3) basic high luminosity design compatible with polarization mode and monochromator mode. (4) stable and reliable operation with optimum average luminosity of 72% peak luminosity.

The common strategy chosen in other new generation colliders to achieve high luminosity, including micro-β with β^*_y=1cm, multi-bunch high current beam about 570mA with 86 bunches per ring, small crossing angle collision, is adopted for the BTCF main scheme. The BTCF machine design lays emphasis on the flexible lattice with an efficient and multi-functional interaction region, and the compatibility of different modes. Table 3 lists the main machine parameters for BTCF high luminosity mode with a horizontal crossing angle. The design details on high luminosity, polarization and monochromatic modes are reported elsewhere[16][18].

Table 3. Machine parameter of the BTCF high luminosity mode

Beam energy E (GeV)	2.0
Circumference C (m)	385.447
Revolution frequency f_0 (MHz)	0.778
Crossing angle at IP $2\phi_c$ (mrad)	5.2
β -function at IP β^*_x / β^*_y (m)	0.65/0.01
Dispersion at IP D^*_x / D^*_y (m)	0.0/ 0.0
Betatron tunes Q_x / Q_y	11.75/11.76
Momentum compaction α_p	0.014
Synch. rad. loss/turn U_0 (KeV)	172
Damping time $\tau_x / \tau_y / \tau_z$ (ms)	30/ 30/ 15
Natural emittance ε_{x0} (nm)	138
Vertical emittance ε_y (nm)	2.1
Momentum spread σ_e	5.84×10^{-4}
Synchrotron tune Q_s	0.068
Natural chromaticity Q'_x / Q'_y	-17/-35
Total current per beam I (A)	0.57
Number of bunches k_b	86
Particles per bunch N_b (10^{11})	0.54
RF frequency f_{rf} (MHz)	476
RF voltage V_{rf} (MV)	6.8
Natural bunch length σ_l (cm)	0.76
Beam-beam effect ξ_x / ξ_y	0.044/0.04
Luminosity L ($cm^{-2}s^{-1}$)	1×10^{33}
CM energy spread σ_ω (MeV)	1.7

The collider physical and technical issues, such as the beam instabilities, background masking, injection and injector, hardware systems like SC magnets and SC cavity as well as vacuum system etc., were also roughly considered and analyzed, some of them will be further investigated in the future R&D project.

4.2 BEPC-II

Upgrading BEPC by means of multi-bunch collision like CESR, namely BEPC-II, is a challenging way to reach the luminosity up to 10^{32} cm^{-2}s^{-1} at 2.0GeV. Its pretzel scheme can increase the number of colliding bunches at one interaction point in the single storage ring while avoiding all the other parasitic collisions. In BEPC-II, the pretzel orbits generated in horizontal plane and vertical plane by DC separators were considered. As a horizontal pretzel orbit case shown in Figure 6, its operating tunes were designed to be Q_x=5.84 and Q_y=6.76, 6 bunches at most per beam could be filled into the pretzel orbit. The main machine parameters of BEPC-II are listed in Figure 4.

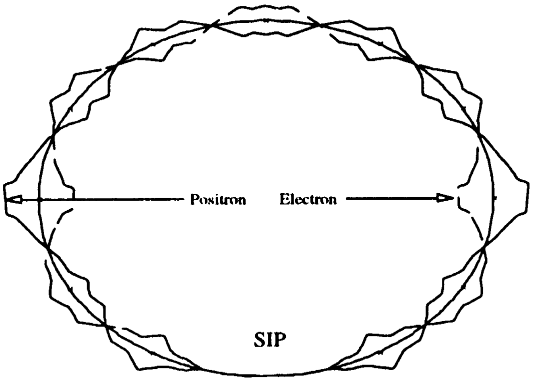

Figure 6. BEPC-II pretzel orbit

Table 4. Main parameters of BEPC-II

Beam energy E (GeV)	2.0
Circumference C (m)	240.4
Bending radius ρ (m)	10.345
Number of bunches k_b	6×2
Number of IP N_{IP}	1
β -function at IP β^*_x / β^*_y (m)	1.2/0.02
Bunch length σ_l (cm)	1.5
Bunch current I_b (mA)	26
Bunch space S (m)	40.07
Total current I_t (mA)	312
RF frequency f_{rf} (MHz)	500
RF voltage V_{rf} (MV)	3.5
Beam life time τ (hr)	>4
Design Luminosity L ($cm^{-2}s^{-1}$)	1.0×10^{32}

Except for realizing the multi-bunch collision by employing the pretzel orbit in single ring, BEPC-II has many features like BTCF, such as micro-β at the interaction point, multi-bunch high current beam etc. However, in terms of the beam dynamics issues, BEPC-II is more complicated due to the pretzel orbit induced. In the last few years, many important issues on BEPC-II has been preliminarily investigated[9][19][20]. The lattice design with the solenoid coupling compensation and the chromaticity correction was conducted, the beam instabilities and beam-beam effects were analyzed, the physical aperture and beam injection scheme were examined, the related hardware systems upgrades were also discussed. All these corresponding investigations are still going on now, and some experiments on pretzel scheme are expected to be conducted at BEPC in the coming years.

4.3 R&D for BTCF and BEPC-II

It is obvious that the best choice for future high luminosity collider in Tau-Charm energy region is BTCF. However, its construction budget is several times of that for BEPC-II. Since most advanced technologies adopted in both BTCF and BEPC-II are very similar, as shown in Table 5, and some of them should be carefully studied before making the final decision and construction, the R&D project on the key common issues extracted from the two colliders were proposed to the Chinese Academy of Sciences last year.

The R&D will focus mainly on optimizing and finalizing the overall design of BTCF and BEPC-II, conducting machine studies at BEPC and other e^+e^- colliders, developing a few key prototypes on which no experience existed, and establishing advanced technology basis such as SC cavity etc.

Table 5. Main technical means for BEPC_II and BTCF

	BEPC-II $L=1.0\times10^{32}cm^{-2}s^{-1}$ E=2.0GeV	BTCF $L=1.0\times10^{32}cm^{-2}s^{-1}$ E=2.GeV
Multi-bunch High current Collision	Single ring Bunch number: 6×2 Current: $156\ mA\times 2$ High pumping rate vacuum system Low outgassing vacuum chamber Rearrangement of IR and upgrade detector Beam feedback system High precision beam diagnostic system Improving injection sys. Improving Linac	Double ring Bunch number :86/ring Current: 565mA/ring High pumping rate vacuum system Low outgassing vacuum chamber New design of IR and detector Beam feedback system High precision beam diagnostic system New injection system Improving Linac
Micro- β scheme	β_y^* =2cm Single IP and head-on collision Bunch length: 1.5cm 500MHz SC RF system Low impedance vacuum chamber SC or permanent quad. In detector	β_y^* =1cm Single IP and small crossing angle collision Bunch Length: 0.76cm 500MHz SC RF system Low impedance vacuum chamber SC insertion quadruple in detector

On the other hand, it is essential to incorporate the experience gained from the two B-Factories (KEK-B and PEP-II) and Φ-Factory (DAΦNE) as well as CESR and the BEPC upgrades, which will give us a great help to make our final decision.

5 SUMMARY

The BEPC has been well operating for about 9 years with fruitful achievements in high energy physics experiments and synchrotron radiation applications. The BEPC luminosity upgrades were carried out and the luminosity gain by a factor of 1.5 was achieved at J/Ψ energy. The machine commissioning to obtain the luminosity gain at 2.0GeV and by employing single interaction point scheme was scheduled this year. The feasibility study of BTCF was completed with a positive review, the initial design of BEPC-II was carried out with a feasible proposal. The corresponding R&D program of BTCF combined with BEPC-II was planed last year, and is expected to be approved in the coming years.

6 REFERENCES

[1] S.X.Fang, S.Y.Chen, Proc. 14th Int.Conf.on High Energy Acc. (1989) 51.

[2] S.X.Fang, H.X.Yu, Proc. Workshop on BEPC Luminosity Upgrades, IHEP-91-01, (1991) 4.

[3] Y.Wu of BEPC Group, Proc. PAC91 (1991) 180.

[4] C.Zhang of BEPC Group, Proc. 15th Int. Conf. on High Energy Acc. (1992) 84.

[5] S.H.Wang of BEPC Group, Proc. PAC95 (1995).

[6] S.H.Wang of BEPC/BTCF Group, Proc. APPC 97 (1997).

[7] Feasibility Study Report on BTCF, IHEP-BTCF Report-03, October 1996.

[8] C.Zhang, Proc. Workshop on BEPC Luminosity Upgrades, IHEP-91-01, (1991) 178.

[9] L.F.Wang, Ph.D Dissertation, IHEP, 1997.

[10] Z.Y.Guo, et al, Proc. PAC97(1997).

[11] J.Wang, et al, Proc. Annual Conf. of BEPC (1996) 4.

[12] J.J.Zhao, et al, Proc. 6th China-Japan Joint Symp. on Acc. (1996) 317.

[13] X.C.Kong, et.al, Annual Conf. of BEPC (1996)17.

[14] S.M.Tang,et.al, Annual Conf. of BEPC (1996)244.

[15] Y.Z.Wu of BTCF Group, Proc. PAC97 (1997).

[16] N.Huang, et al, These Proceedings (1998).

[17] Y.Z.Wu, Q.L.Peng, Proc.PAC97 (1997).

[18] D.Wang, Internal Report IHEP/BEPC/AP/97-26 (1997).

[19] L.F.Wang, Proc.PAC97 (1997).

[20] N.Huang, Internal Report, IHEP-BEPC-II (1997).