BEPC Status and Plans

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ABSTRACT

BEPC operation status over the past years with the results in exciting physics and integrated luminosity enhancement are summarized. The status of the luminosity upgrade project is described. The future plans on tau-charm factory and new generation light source are presented.

1. OPERATION STATUS

The Beijing Electron Positron Collider (BEPC) [1,2] has been well operated for about 6 years since 1989, serving for High Energy Physics (HEP) as a collider and for Synchrotron Radiation Research (SR) as a light source. It operated 5500 ~ 6000 hrs. each year. The typical operation statistics in a year (e.g. 1994) for HEP, SR, machine study (MD), injection (INJ), recovering & commission (RC) and failure time is listed in Table 1, showing the operation efficiency is higher than 90%.

Table 1. Statistics of BEPC operation in 1994

	HEP	SR	MD	INJ	RC	FALL	Total
Time (hrs)	1928	1182	847	741	818	292	5808
Percent-age	33.2%	20.4%	14.6%	12.8%	14.0%	5.0%	100%

In the HEP runs, due to the high luminosity and the reliable operation, BEPC cooperated with the detector Beijing Spectrometer (BES) has acquired a plenty of data, as shown in Table 2, in which the main operation parameters (Energy, Current, Peak luminosity and the average luminosity per day) are also listed.

Table 2. Operation parameters and acquired data

	J/ψ	$\tau^-\tau^+$	ψ'	$D_s(D_0)$
Energy (GeV)	2×1.548	2×1.777	2×1.843	2×2.015
Max. current (mA)	50	55	60	65
Max. lumi. ($10^{30}cm^{-2}\cdot s^{-1}$)	3 - 4	4 - 5	5 - 6	5 - 7
Int. Lumi. or Event per day	100 K/day	120 nb^{-1}	107 nb^{-1}	161 nb^{-1}
Total Event or Int. Lumi.	9×10^6	4.74 pb^{-1}	3×10^6	23.5pb^{-1}

BEPC/BES is an unique machine which has operated in the tau-charm energy region, and fortunately it has obtained a lot of important experimental results and exciting physics, among which are:

* Having more precisely measured τ lepton mass as [3]

$$m_\tau = 1776.9 \pm 0.2 \pm 0.2 \text{ MeV}$$

It is furthermore precise in statistical error than the one we firstly measured in 1992 by fitting data with likelihood method using more events and more decay modes, and furthermore tend to fit the lepton universality.

* Having confirmed the existence of the $\xi(2230)$, and have discovered its very important new decay modes, $\xi(2230) \to p\bar{p}$ and $\xi(2230) \to \pi^+\pi^-$ with vary narrow decay widths, which is a big progress in understanding its nature and it looks very like a glueball.

In the SR runs, BEPC co-operated with Beijing Synchrotron Radiation Facility (BSRF) has also obtained the rich experimental results in the past years since 1991. About 1000 hrs. and 3500 hrs. beam time per year in dedicated and parasiticmodes respectively are provided to about 80 users units from institutes and universities in China. In the dedicated SR mode, BEPC is operated at 2.2 GeV and 30 ~90 mA with the small horizontal emittance of 70 nm-rad.

In the progress of serving for HEP and SR, BEPC itself has been improved with maintains and machine studies. The main characterization of the improvements is the raise of the integrated luminosity. Table 3 and Fig. 1 show the statistics of BEPC operation at D_s energy (2.015 GeV per beam) in 1992--1994 [4], in which the integrated luminosity per day was significantly increased from 97 nb^{-1} in 1992 to 161 nb^{-1} in 1994, that is with an enhancement factor of 1.65. The main contribution to this enhancement were made by following factors:

Table 3 Statistics of Operation at D_s energy (2.015 GeV) in 1992--1994.

Year	Working days	I_{ini} (mA)	L_{ini} ($10^{30}cm^{-2}\ s^{-1}$)	L_{int}/day (nb^{-1})	L_{int} total (pb^{-1})
1992	68	60.7	5.3	97	6.6
1993	85	56.0	4.0	110	9.3
1994	108	67.0	5.6	161	17.6

* The tunes were optimized and the injection conditions were improved as possible.

* Some beam instabilities related to RF cavities were suppressed by using the HOMs coupler in the BEPC cavities.

* By improving the vacuum situation and the fast protection for RF windows.

* All of the magnets in the ring have been carefully realigned in the summer-shutdown periods, after that much

better closed orbit was obtained and the background was improved.

* By improving the linac operation, e.g. stability and reliability of klystron modulators, so that the injector operation efficiency has been risen.

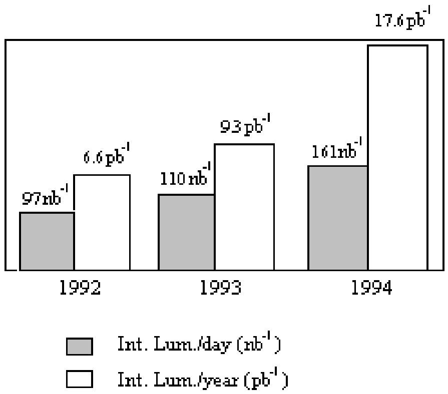

Fig. 1 Integrated Luminosity at Ds energy

2. UPGRADE STATUS

The rich opportunities of high energy physics in BEPC energy region and the exciting physics results obtained with BES encouraged us to upgrade the BEPC luminosity, even though the realized luminosity of 6×10^{30} $cm^{-2}\cdot s^{-1}$ at 2.0 GeV is already met with the design goal. The actions of the upgrade project involve:

* Luminosity upgrade by mainly using mini-β optics, and by using single interaction point collision and by beam emittance control
* Linac energy upgrade
* Control system upgrade and
* Reconstruction of the Detector (BES-II)

The upgrade plan was firstly discussed in 1990. In June of 1991, the workshop on BEPC luminosity upgrade was held in IHEP, and 14 foreign experts were invited to participate this workshop. In May of 1992, IHEP sent an official proposal to the Chinese Academy of Science (CAS), and then to Chinese Government. Finally the upgrade project was officially approved in May of 1993. Since then the project is going well, even facing some technical difficulties.

2.1 Mini-β Optics

The most effective way to get a significant gain of luminosity is to use the mini-β optics. Since keeping the beam current constant, the luminosity is inverse proportional to the vertical β function at interaction point β_z^* in the case of optimum coupling between horizontal and vertical motions.

In the routine operation with low-β optics in BEPC the β_z^* is 8.5cm, and in the primary design of the mini-β optics, β_z^* of 3.6 cm was chosen [5] by using a pair of permanent quadruples which installed inside the detector and very near the interaction point (say 1.3 m away from the IP), as shown in Fig.2.

The most crucial factor for the mini-β optics in BEPC, having a ring with lower energy of 2.0 GeV and smaller circumference of 240 m, is bunch length σ_l and its lengthening. In the routine operation of BEPC the ratio of β_z^*/σ_l would be about 1.2, which makes higher luminosity and better signal to noise ratio. It means the σ_l should be about 3.0 cm in the mini-β optics, while at present σ_l is about 5 ~7 cm.

To shrink the bunch length to about 3.0 cm, a method of having higher RF voltage in the cavities was chosen. By adding two cavities (used in SPS, CERN) and re-grouping the available RF power supplies, together with two BEPC cavities, a total RF voltage of 2.4 MV can be expected. With this mini-β scheme, the luminosity gain factor of 2 ~ 3 was expected.

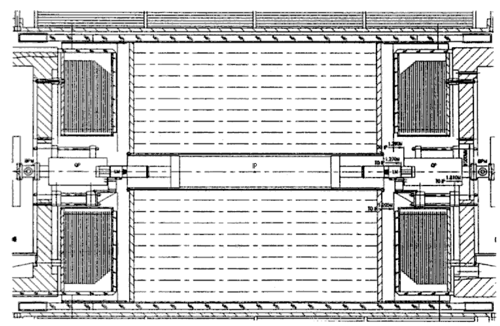

Fig. 2 Mini–β QP in Detector

To measure the real bunch length with higher RF voltage is the most important issue in examining the BEPC mini-β scheme. As the first SPS cavity was put into operation, and the higher RF voltage of 1.5 MV was obtained in the Autumn of 1993, a great number of bunch length data with different RF voltage, different beam energy and currentwere obtained by using streak camera and simultaneously by using beam spectrum analysis method. By fitting all of the measured data, we obtained the scaling law of the bunch length in BEPC storage ring: [6]

$$\sigma_l(cm) = 0.404\left[\frac{I_0(mA)\alpha_p}{E_0(GeV)\upsilon_s^2}\right]^{1/2.80}$$

By this scaling low one find that for E_0 = 2.0 GeV, V_{rf} = 2.0 ~ 2.4 MV and I_b = 35 mA (as the same as in routine low-β operation) then σ_l will be 4.2 ~ 3.9 cm, which is longer than the previously estimated one. If the optimum β_z^*/σ_1 is still about 1.2, then the corresponding β_z^* is about 5cm, which is larger than the design value. With β_z^*= 5cm, the luminosity gain factor is only about 1.7.

If one increase the beam current upto 46 mA, which meets the saturated beam-beam parameter $\xi_z = 0.04$, then in the case of $\beta_z^* = 5$ cm, the luminosity gain factor could be reached to about 2, even though the bunch length will be increased to 4.5 cm.

Since the designed BEPC lattice is reliable and flexible, the calculation with $\beta_z^* = 5$cm optics has shown [7] that without adding any hardware in BEPC the $\beta_z^* =$ 5cm optics can be reached just by moving the insertion quadruples Q1 and Q2 towards to the interaction point by a distances of 37 cm and 47.7 cm respectively, and a better dynamic aperture can be also obtained.

To finally realize the mini-β optics in BEPC, we should furthermore compress the bunch length, for which one of the possible way is by decreasing the longitudinal coupling impedance of the storage ring. The calculation and mea-surements on impedance with different elements in BEPC have shown that the 4 kickers and 40 bellows made the main contributions to ring impedance. Collaborated with Tsing-hua University a special group has been organized to furthermore study the precise measurement and impro-vement on impedance. The primary results have shown that with the improved bellow, its impedance can be reduced from 0.06Ω to 0.017Ω/each, and with slotted kickers, its impedance can be reduced from 0.35 to 0.074Ω/each [8], so that their contribution to the ring impedance could be reduced by a factor of 3 ~5. We have to make more effort on trying to reduce the ring impedance with machine study and finally realize the mini-β scheme in BEPC.

The mini-β permanent magnet, made of NdFeB, has the length of 500 mm and the field gradient of 8T/m. It consists of 10 magnetic rings longitudinally, and each ring consists of 24 magnet pieces. This configuration makes the harmonic components of magnet much small. The prototype of single-ring and double-ring have been made, and the measured harmonic contents after tuning are about a few of 10^{-4} [9].

The two SPS cavities have been put into operation in the Autumn of 1994. Together with two BEPC cavities, the total RF voltage of four cavities in the operation can be reached to 2.0 MV. The two additional power supplies for Q1 and Q2 were prepared for the mini-β scheme and for the study on single interaction point.

2.2 Linac Energy Upgrade

The linac offers the electron and positron beams with the energy of 1.3 GeV into the storage ring at present. The beams with higher energy from the linac will make the injection more effective. The linac has 16 Klystrons with the average RF output of about 19 MW each in routine operation, and has 13 energy doubles with the energy multiplication factor of 1.4 each.

The procedure of the linac energy upgrade includes[10]:

* Replacing three sets of old Klystrons and old modulators by new constructed 65 MW Klystron and 150 MW modulators. With careful consideration to reliability and EM compatibility, the prototype of the new modulator has been designed and constructed. The measured voltage output shows that it meets with the design requirement. A 3.7 μs wide pulse with 354 kV voltage and 430 A peak current were successfully generated [11]. Other three new modulators have also been fabricated. The prototype of the new Klystron has been made in China and delivered to IHEP in February 1995. The primary test of the new Klystron is being tested on the new constructed test station [12]. Other three new Klystrons are being constructed.

* Increasing the RF pulse width from 3.0 μs to 3.5 μs or more wider so that higher energy multiplication factor can be achieved.

Totally the linac energy will be increased to 1.75 GeV, which can make the full energy injection into ring for J/Ψ and $\tau^+\tau^-$ experiments.

2.3 Control System Upgrade

The BEPC control system has been running safely and reliably for 40,000 hours since it was built at the end of 1987. But the original control system was proved to be undesirable in many aspects, such as low CPU power, limited memory of the VAX/750 control computer and some other hardware problems.

The upgrade of the control system is to transform this system into a distributed one based on DECnet to make it faster in response and more reliable in performance. The new control system is shown in Fig.3.

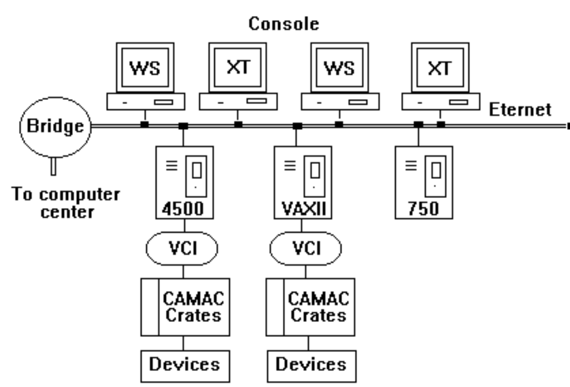

Fig. 3 Upgraded control system structure

With two VAX4090 workstations appended on DECnet used as the new console, the old one and its adapter Grinnell are eliminated. The VAX4500 and Micro VAXII computer are connected with DECnet to carry out the real time control. Replacing VAX750 and the VCC with the Qbus/CAMAC adapter interface, both VAX4500 and VAXII can independently control all BEPC equipment.

The upgrading was carried out without interrupting the normal operation of BEPC, therefore all of the low level CAMAC system have not been changed. A lot of software development have also been done to meet with the upgrade requirement.

The upgrade of BEPC control system has been finished and the new system was put into use in October 1994[13]. Now, the new BEPC console is a friendly man-machine interface. We use two workstations and two VAX computer systems as on-line control, the system is much more reliable. The CPU power and memory resource have also been increased, so the response time is shortened.

3. FUTURE PLANS

3.1 Tau-Charm Factory (τCF)

Even though there were four τCF workshops in the world since 1989 to 1993, to confirm the necessity and the feasibility of a τCF in existence of two B-factories in the world an international τCF workshop [14] was held again at Stanford, California in August 1994. The meeting has concluded that:" In certain basic areas of particle physics, such as the search for glueballs, possible CP violations in lepton system and the charmonium structure, the τCF provides an unique facility". Since such searches can only be precisely made near their production threshold with a τCF. The meeting also encouraged us to construct a τCF in future at IHEP, Beijing in the frame of international collaboration.

A primary design of a τCF in Beijing has been made [15]. It is a two-ring, one collision electron-positron collider with a design luminosity of 10^{33} $cm^{-2}\cdot s^{-1}$ and an energy range of 3 ~ 6 GeV. Its construction can be carried out on the site of the existing IHEP complex and very near the BEPC as shown in Fig.4, and it can use the existing linear accelerator injector.

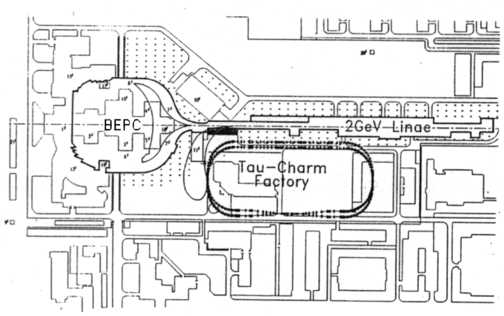

Fig.4 Layout of Beijing τCF

The performance comparison between τCF and BEPC is as shown in Table 4. The main ways to approach the τCF luminosity from the one of BEPC are probably as follows:

* By using a multi-bunch scheme to reach the beam current of 550 mA in τCF, which has a current enhancement factor of 13.75.

* By using a micro-β scheme, so that the β_z^* is 1 cm in τCF, which is 1/5 of the one in BEPC.

Table 4 The comparison between τCF and BEPC

	BEPC	τCF
Number of bunches	1	32
Bunch separation (m)	240.4	11.48
Particles per bunch	2.16×10^{11}	1.32×10^{11}
Bunch current (mA)	40	17.16
Current per beam(mA)	40	550
β- function at IP (cm)	5	1
Bunch length (cm)	4.5	1.0
B-B parameter	0.04	0.04
Luminosity($cm^{-2}\cdot s^{-1}$)	1.5×10^{31}	1.0×10^{33}

So that the total luminosity enhancement factor of 68.75 could be achieved. The construction of Beijing τCF, as the same as CERN design [16], would probably have following three phase program: 1) Standard phase, conventional design with high luminosity at the energy of τ-lepton production threshold. 2) Monochromatic phase at the energy of J/Ψ resonance, with low emittance and a non-zero vertical dispersion at IP, to study the CP-violation. 3) Longitudinal polarization phase, combined with monochromatic collision. For the first two phases, the primary parameters are listed in Table 5.

Table 5 Primary parameters of Beijing τCF

	Standard	Monochromator
Beam energy (GeV)	2.0	1.5
Circumference (m)	367.5	367.5
β_x^*/ β_z^* (m)	0.2/0.01	0.01/0.15
Dispersion at IP (m)	0.0	0.35
Momentum compaction	0.022	0.008
Natural emittance (nm)	251	10 (J_x=2)
Energy spread (10^{-4})	5.4	8.0
RF frequency (MHz)	499.58	499.58
RF voltage (MV)	9.0	9.0
Number of bunches	32	32
Current/beam (mA)	550	215
RMS bunch length (cm)	1.0	0.78
B-B parameter (hr)	0.04/0.04	0.031/0.015
Beam life time (hr)	4.8	1.5
CM energy spread (MeV)	1.53	0.105
Luminosity ($cm^{-2}\cdot s^{-1}$)	1×10^{33}	2.2×10^{32}

The design and construction of the τCF should be started with a long term R&D, since it faces a lot of serious challenges in the performance and techniques required both in accelerator and detector. The cost estimation to construct the Beijing τCF is about 120 million USD, a quite big amount for China. Therefore IHEP should make its great efforts, with the national and international collaboration, to prepare this project both in technical and economical aspects. Fortunately the feasibility research of the Beijing τCF was officially approved by Chinese government recently, which will take one and an half year, making a conceptual design of the Beijing τCF as well. Then it might be followed by a three or four year's R & D. The construction project is expected to start around 1999.

3.2 The New Generation Light Source

Currently the BEPC dedicated SR operation time is only about 20% of the total one, but above 80 users need about 10 ~ 20 times more for their interested experiments. On the other hand, for the parasitic mode it is not easy to well operate the BEPC both as a collider and a light source.

Due to these reasons, a proposal to construct a third generation light source in China [17] (say CLS) is being made at IHEP. The CLS could be built by converting the existing BEPC to a fully SR facility if the Beijing τCF will be constructed in the east side of BEPC, or by constructing a fully new storage ring in the west side of BEPC, and the existing linac can be used as the injector. The another possibility is to construct the CLS in Shanghai, if it could be co-supported by Shanghai city, which is being also discussed recently.

Some principles of designing the CLS have been consi-dered as follows:

* The energy of CLS will be 2.0 ~2.5 GeV, so that will be in median size (190 ~ 250 m in circumference) compared with 0.8 ~1.0 GeV and 6 ~ 8 GeV machines.

* It uses two kinds of bending magnets. One is the conventional magnets with the field of 1.0 ~1.3 T, which produce the photons with the energy of 2.5 ~ 25 keV. Another one is the superconducting magnets, located in the middle of some magnetic periods, with the field of 4 ~5 T, so that the photon's energy will be 10~60 keV, which is equivalent to the one produced from a light source of 5~6 GeV. Therefore the CLS will cover the full spectrum.

* It has two super-straight sections (say about 15 m long each), which remain the rooms behind to develop the new kind of light source, combined probably with free electron laser.

The primary design of the CLS is being made [18]. The Lattice of FBA with 8 periods is preferred to get very small beam emittance (≤5 nm·rad) and enough dynamic aperture as well. In each period there are five bending magnets. In the four periods, there is a superconducting bending magnets in the middle of each period. Due to very small beam emittance, high beam current (~300mA) and well performed insertion elements (undulators and wigglers) in the straight sections, one can get the lights from CLS with the high brightness of 10^{15} from bending magnets, 10^{16--17} from wigglers and 10^{19-20} ph/s·mm^2·mrad^2·0.1% BW from undulator.

The CLS-proposal is going to the Chinese Government, with a proposed schedule of having a two year's R & D and followed by a five year's construction period.

4. CONCLUSION

The BEPC has been well operated for about 6 years. In the HEP runs, due to the high luminosity and reliability BEPC co-operated with the detector BES has acquired a plenty of data and obtained a lot of exciting physics. In the SR runs, BEPC co-operated with BSRF has also obtained the rich experimental results in the different scientific areas. BEPC itself has been improved as well on its integrated luminosity.

The luminosity upgrade project of BEPC, including mainly use of mini-β optics, linac energy upgrade, control system upgrade and reconstruction of the detector, is going well, even facing some technical difficulties. A luminosity gain factor of 1.5 ~ 2.0 is expected in the coming years and of 3.0 ~ 4.0 is also planed in the near future by improving the ring impedance and others.

For the future plans, the Beijing Tau-Charm Factory and the Chinese new Light Source are being proposed.

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