LUMINOSITY ENHANCEMENT AND PERFORMANCE IN BEPCII*

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Abstract

The upgrade project of the Beijing Electron Positron Collider, BEPCII, made a big progress of its luminosity during the last high energy physics (HEP) run from late 2010 to mid of this year. The luminosity reached nearly 2/3 of the design value, after some measures were taken during the commissioning. Efforts done on the machine and luminosity commissioning from last IPAC are summarized in this paper.

INTRODUCTION

Being consisted of a linac, two transport lines, storage rings and detector, the BEPCII runs as a factory-like collider for HEP experiment, and a dedicated synchrotron radiation (SR) facility as well. As described before [1], [2], the BEPCII storage rings are shown in Fig.1, which are two rings placed in parallel for collision and one ring connected by the two half outer rings run for SR users.

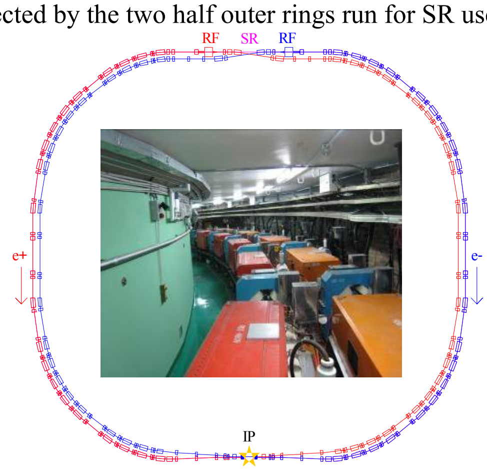

Figure 1: BEPCII layout and its real tunnel (blue: e^- ring, red: e^+ ring)

The BEPCII was designed as a charm-tau factory-like collider with the designed luminosity of $3\text{–}10\times10^{32}cm^{-2}s^{-1}$ at the beam energy of 1.89 GeV. Besides the collision, the BEPCII can be run at 2.5 GeV as an SR user facility. The main design parameters are listed in Table 1.

Table 1: Main design parameters of the BEPCII

Beam energy for collision	GeV	1.89
Beam current in collision	mA	910
Beam energy for SR	GeV	2.5
Beam current in SR mode	mA	250
Luminosity	$cm^{-2}s^{-1}$	$3\text{–}10\times10^{32}$

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The luminosity tuning, accompanied with the machine commissioning started from mid of July, 2008, when the HEP detector was rolled in the interaction point (IP). It was quite fast to get to the luminosity of $1\times10^{32}cm^{-2}s^{-1}$, which is one order higher than that of the BEPC. From the end of 2008, the trend of luminosity increasing slowed, and was proved later that two slots of an extra profile on the positron ring caused a quadrupolar longitudinal oscillation, which reduced the luminosity along the bunch train [2]. After removing the profile, we commissioned the beam again, and the luminosity quickly reached 1/3 of the designed value, shown in Fig. 2.

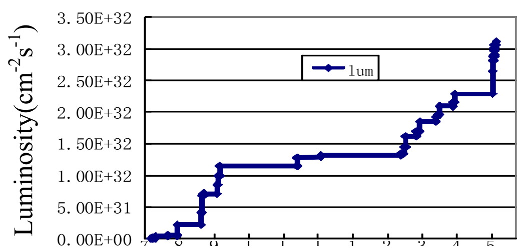

Figure 2: Luminosity trend from Sept. 2008 to May 2009.

During the summer shutdown in 2009, the longitudinal feedback systems were installed on both e□ and e+ rings to cure the dipolar longitudinal oscillation. The bunch by bunch luminosity was then similar to each other in one bunch train, shown as Fig. 3.

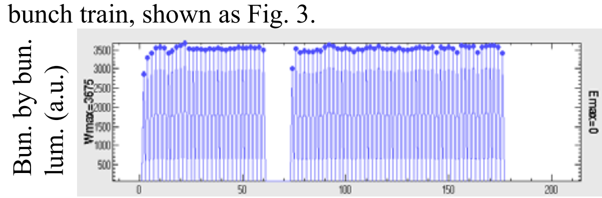

Figure 3: Bunch by bunch luminosity with longitudinal feedback system on.

In this paper, we will mainly focus on the luminosity tuning together with the detector background reduction in the HEP run of 2010 – 2011, and during which the storage rings successfully worked on the near half integer of horizontal tune with high beam currents. Performance of the machine for luminosity delivery will be also covered. Some discussions and possible measures for higher luminosity will be given at last.

BEAM OPTICS CORRECTION ON RINGS

During the summer shutdown of the machine in 2010, we first corrected the big horizontal misalignment of the east superconducting quadrupole and two nearby dual-aperture quadrupoles. This misalignment is believed to cause the large background of the detector at higher beam currents, though the closed orbit distortions due to this error were corrected accordingly. Beam based alignment was used in the BPMs' offsets measurement after the start of the machine. Beam optics correction was carried out at the mode of $\nu_x = 0.53$, at which the two collision rings ran for HEP experiments before.

We then corrected the beam optics of the whole ring by means of applying fudge factors to each quadrupole, with the measured response matrix. Different from the similar procedure of optics correction, we considered the two superconducting quadrupoles near the IP instead of treating them as ideal magnets. With this improvement, the abnormal fudge factors of Q02's in the IR, which kept more than 10% when the two superconducting quadrupoles were not included in optics correction, reduced a lot. As a result, the measured β_y^* at IP is closer to the design value. Figure 4, as an example, shows the result of the measured β function along the e⁻ ring (BER) compared with the calculated value.

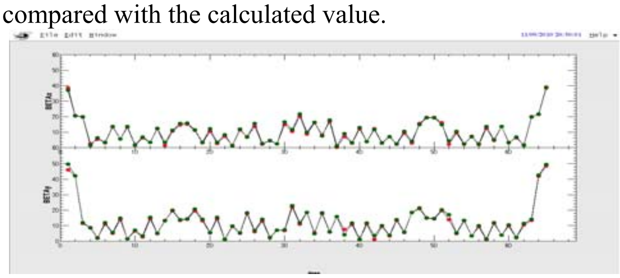

Figure 4: β function measurement in the e- ring (green: calculated value, red: measured value).

The e^+ ring (BPR) had the similar results on the measurement of β function, and the relative errors were around 10%. The closed orbit distortions (C.O.D.) of two rings were corrected globally together with the beam optics correction. Having the corrected tunes and the β functions along the ring, we corrected the C.O.D. to be within ±1 mm by means of response matrix. The variation of beam energy due to the changes of C.O.D. correctors should be considered, to keep the beam energy unchanged during any correction. With these methods, the main beam parameters were corrected closer to their theoretical values, listed in Table 2.

Table 2: Some beam parameters after optics correction

Beam parameter		BPR		BER	
		Design	Meas.	Design	Meas.
Transverse tune	Hori.	6.536	6.5357	6.537	6.5345
	Vert.	5.600	5.6050	5.607	5.6063
Corrected chromaticity	Hori.	1.0	1.6	1.0	1.4
	Vert.	1.0	1.1	1.0	1.1

LUMINOSITY COMMISSIONING

After finishing the beam optics correction, we moved the horizontal tunes of two rings towards 0.51, near the half integer at the tune diagram, to get higher luminosity. Since it was not easy to measure the response matrix by changing the quadrupole strength one by one, we applied the fudge factors of each quadrupole got from the mode of 0.53. The result looked very good and the transverse tunes were very close to the expected ones.

Background Reduction

In the first half year of 2010, the BEPCII could not work at the tune range of near half integer with high beam current in both rings due to the high background in the main drift chamber (MDC) of the detector, BESIII [2]. The background comes mainly from beam-gas scattering and Touschek effect, and also from the beam loss due to big orbits or other unknown sources around rings. In this run's luminosity tuning, after we got a quite good luminosity, we tried to lower the dark current at the most inner layers of the MDC, which was the main indication of background.

The dark current (labelled as S5) reduction started from the orbit correction of the whole ring. Before orbit correction, S5 was as big as 14μA at 325mA beam current and 40 bunches. After the orbit was corrected carefully, S5 was decreased to 6μA. Then, optimization of the beam separation at the north crossing point (NCP) made S5 another 50% reduction. After these optimizations, we could increase the beam current and bunch number for collision, and the tilt at the IP became another knob to decrease S5. The tunes of both rings and the transverse coupling coefficients are also contributed to lower the dark current. Finally, the dark current S5 at high beam current was at an acceptable level for data taking. Figure 5 gives the optimization of the dark current to MDC.

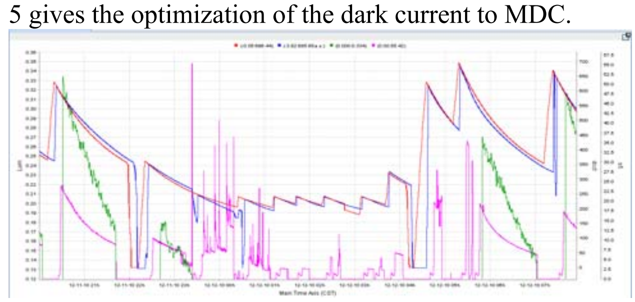

Figure 5: Dark current reduction with luminosity tuning. (Red and blue: e^+ and e^- beam current; green: luminosity; pink: dark current S5)

Luminosity Enhancement

With this improved background, we injected beams for collision with 80 bunches and increased the beam current gradually. The low level of RF (LLRF) was also tuned to accommodate high beam current. Another progress in the hardware done in the summer shutdown last year was the change of single polarity of the power supplies of skew quadrupoles to dual polarity. With this improvement, skew quads can be used to tune the transverse coupling more freely than before.

From March 2009, BEPCII could provide synchrotron light from 5 beam lines when it delivered luminosity to HEP experiments. Among these 5 beam lines, 2 are from the wiggler 1W2, which is located at the center of the arc of region I, shown in Fig. 1. The luminosity was then commissioned with this wiggler magnet on (gap = 41 mm), and reached 5.94×10^{32} $cm^{-2}s^{-1}$ with the measures of moving the horizontal tune to 0.506 in both rings and optimizing transverse coupling. Then the bunch number for collision was increased from 80 to 88, making another luminosity record, 6.492×10^{32} $cm^{-2}s^{-1}$. The luminosity of 88 bunches was linearly increased from 80 bunches, indicating a good signal for more bunches to get higher luminosity. Figure 6 shows the luminosity evolution from last Nov. to this April.

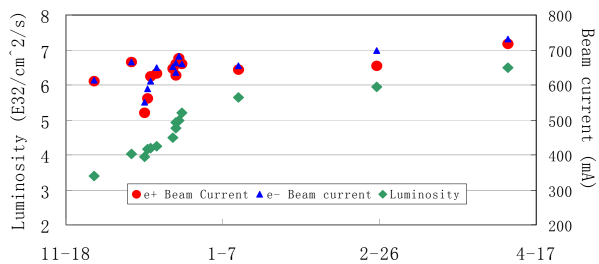

Figure 6: Luminosity enhancement during HEP running.

In Fig. 6, we can see that after it was above 5×10^{32} $cm^{-2}s^{-1}$, the luminosity got higher and higher, but the beam current increased slowly. This luminosity profit came from the coupling optimization. If we put typical data of luminosity of the past 3 years, we can easily find the luminosity progress, as shown in Fig. 7. In Fig. 7, one can know the luminosity enhancement got from moving the transverse tune close to half integer and from the increase of beam current, respectively.

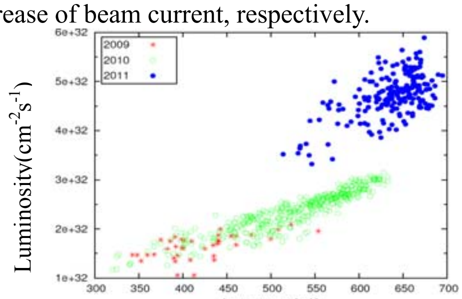

Figure 7: Luminosity in three years running.

Figure 8 compares the single bunch luminosity with the simulation result at different transverse coupling, and also the vertical beam-beam parameters got in operation.

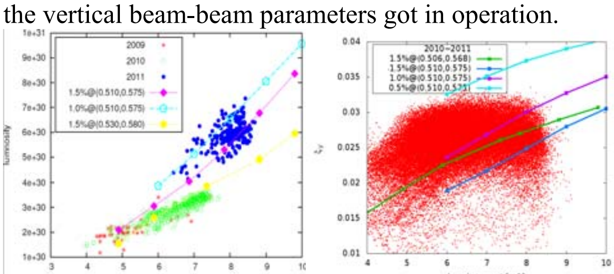

Figure 8: Single bunch luminosity (left) and ξ_y (right) at different transverse coupling (dots joined by lines).

Operation of HEP Running

With the higher luminosity compared to last HEP run, the BEPCII can deliver more integrated luminosity than before. A record of 29 pb^{-1}/day was reached in this April. During this HEP running, the machine was tuned to ψ(4010) energy (beam energy =2.005 GeV) to take data of 500 pb^{-1}, after a total amount of 2.0 fb^{-1} of ψ(3770) was obtained. Luminosity reached 6.5×10^{32} $cm^{-2}s^{-1}$ again at the beam energy of 2.005 GeV. Figure 9 shows the integrated luminosity in the past HEP run. Table 3 summarizes some main parameters the BEPCII storage rings reached in HEP.

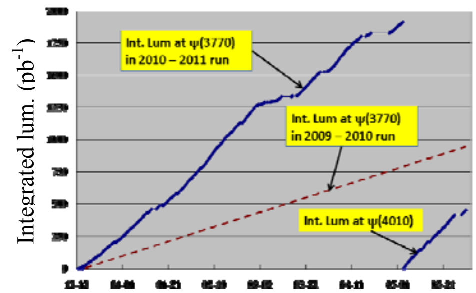

Figure 9: Integrated luminosity delivered to HEP.

Table 3: Main parameters achieved in HEP running

Parameters	Design	Achieved	
		BER	BPR
E (GeV)	1.89	1.89, 2.01	1.89, 2.01
I (mA)	910	~800	~800
I_b (mA)	9.8	~9.0	~9.0
N_b	93	80 – 88	80 – 88
ξ_y	0.04	0.0327	
$L(\times10^{32}cm^{-2}s^{-1})$	10	6.492	

SUMMARY AND LUMINOSITY FORESEEING

The luminosity of BEPCII achieved this year during HEP operation doubled to the level of 2009 – 2010, and the delivered integrated luminosity was more than doubled as well. Furthermore, this was got when an SR wiggler worked for users when the detector took data. The luminosity enhancement comes mainly from moving horizontal tune to half integer, higher beam current, and optimized transverse coupling. The reduced background of detector guaranteed the increase of beam current.

The further luminosity enhancement will be focused on more collision bunches with higher bunch current. The non-linearity from the sextupoles located in arc regions, is also considered for larger dynamic aperture and longer beam lifetime. The parasitic beam-beam interaction in the opposite of IP is now being considered, and a luminosity increase will be foreseen in the near future.

REFERENCES

[1] C. Zhang, et al, “BEPCII Status”, PAC’09, Vancouver, May 2009.

[2] Q. Qin, et al, “Status and Performance of BEPCII”, IPAC’10, Kyoto, May 2010.