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DIFFERNET OPTICS WITHIN LARGE ENERGY REGION AT BEPCII

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Abstract

BEPCII is designed at the beam energy of 1.89 GeV. According to the requirements of high energy physics, BEPCII has been operated in the energy region from 1.0 GeV to 2.3 GeV since 2009. The energy region is quite large so that it is very important to select optics for the optimized luminosity. Different optics within different energy region at BEPCII will be introduced in detail in this paper.

INTRODUCTION

Beijing Electron-Positron Collider (BEPC) has been well operated not only for high energy physics, but also for synchrotron radiation application for more than 15 years since 1989. Its upgrade scheme BEPCII is a double-ring collider which two beams have same energies. It aims at the research of τ-charm physics with a designed luminosity of 1.0×10^{33} cm^{-2}s^{-1}, which is about two orders higher than BEPC at the beam energy of 1.89 GeV. The two new rings have been built in the existing BEPC tunnel while keeping the machine as a synchrotron radiation source. According to the requirements of high energy physics, BEPCII has been operated in a large energy region from 1.0 GeV to 2.3 GeV since 2009.

OPTICS OPTIMIZATION AT 1.89 GeV

The main parameters of designed lattice is shown in Table 1. The commissioning of BEPCII at the energy of 1.89 GeV started on June 22nd, 2008. The horizontal tune was moved from 6.530 to 6.505 on May 5th, 2009 for higher luminosity. The data taking at the energy of 1.89 GeV started from the beginning of 2010. The beam current and luminosity were improved step by step, together with the control of detector background and the luminosity optimization systematically. The maximum beam current and luminosity reached 750 mA and 6.49×10^{32} cm^{-2}s^{-1}, respectively until April 28th, 2011. There are two limitations to restrict the luminosity further improvement. One is the beam current, and the other is beam-beam parameter. It's very hard to increase the beam current, especially above 700 mA due to heating problem, which were mainly caused by synchrotron radiation power and high order mode. Several serious hardware failures were happened during the operation, such as kicker magnet, RF coupler, SR monitor, bellows, feedback system, etc. The beam-beam parameter was limited obviously under 0.033 at any bunch current shown in Fig. 1. Bunch lengthening effect was considered to explain the phenomenon.

Table 1: Main Design Parameters of BEPCII

Parameters	Values
Operation energy	1.0~2.1 GeV
Optimized energy	1.89 GeV
Beam current	910 mA
Bunch current	9.8 mA
Circumference	237.5 m
Number of particles	4.5×10^{12}
β function at IP β_x/β_y	1.0 m/1.5 cm
Horizontal emittance	144 nm·rad
Working point υ_x/υ_y	6.53/5.58
Harmonic number	396
Bunch number	93
Bunch spacing	2.4 m
RF voltage	1.5 MV
RF frequency	499.8 MHz
RF cavity number per ring	1
Energy loss per turn	121 keV
Synchrotron radiation power	110 kW
Damping time $\tau_x/\tau_y/\tau_E$	25/25/12.5 ms
Natural energy spread	5.16×10^{-4}
Momentum compaction	0.0235
Natural bunch length	1.35 cm
Crossing angle at IP	11×2 mrad
Beam-beam parameter	0.04
Luminosity	1.0×10^{33} cm^{-2}s^{-1}

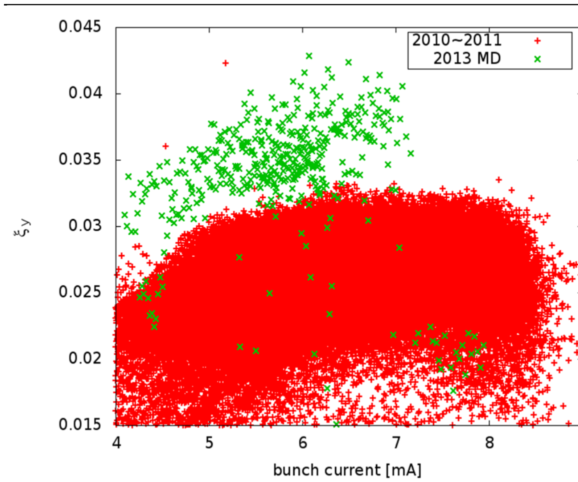

Figure 1: Comparison of beam-beam parameter with the schemes of different bunch lengths.

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There is only one RF cavity for each ring due to the limitation of free space in the tunnel. It's unavailable to suppress bunch length by increasing the voltage of RF cavity. A new lattice was designed to control the bunch length [1] with the main parameters shown in Table 2. The natural bunch length is reduced from 1.35 cm to 1.15 cm by decreasing the momentum compaction from 0.0235 to 0.0170. More collision bunches are required since the designed bunch current is reduced from 9.8 mA to 7.0 mA with lower emittance. The bunch spacing is modified from 4 RF buckets to 3 for more bunches.

Table 2: Main Parameters of Low Momentum Compaction and Low Emittance Lattice

Parameters	Values
Optimized energy	1.89 GeV
Beam current	910 mA
Bunch current	7.0 mA
β function at IP β_x/β_y	1.0 m/1.5 cm
Horizontal emittance	100 nm·rad
Working point υ_x/υ_y	7.505/5.580
Bunch number	130
Bunch spacing	1.8 m
Momentum compaction	0.0170
Natural bunch length	1.15 cm
Beam-beam parameter	0.04
Luminosity	1.0×10^{33} cm^{-2}s^{-1}

Table 3: Main Parameters of Low Momentum Compaction and Large Emittance Lattice

Parameters	Values
Optimized energy	1.89 GeV
Beam current	910 mA
Bunch current	8.3 mA
β function at IP β_x/β_y	1.0 m/1.35 cm
Horizontal emittance	122 nm·rad
Working point υ_x/υ_y	7.505/5.580
Bunch number	110
Bunch spacing	1.8 m
Momentum compaction	0.0181
Natural bunch length	1.15 cm
Beam-beam parameter	0.04
Luminosity	1.1×10^{33} cm^{-2}s^{-1}

A dedicated machine study to test the new lattice was performed during February 28th to March 7th, 2013. The restriction to the beam-beam parameter was broken, as shown in Fig. 1. The maximum beam-beam parameter reached 0.043. During the commissioning with 130 bunches, the transverse multi-bunch instability was too serious to keep beam stable by the feedback system. The maximum stable beam current was 750 mA while the maximum luminosity reached 7.08×10^{32} cm^{-2}s^{-1}. The beam-beam parameter was reduced about 20% comparing to the less bunch number case.

The bunch number should be controlled as less as possible to keep beam stable without upgrading feedback system. The lattice with low momentum compaction was improved. The main parameters is shown in Table 3. The emittance was increased from 100 nm to 122 nm to increase the collision bunch current so that the bunch number can be relatively less. The beta function at the IP was reduced from 1.5 cm to 1.35 cm. Dedicated machine studies to test the updated lattice at the beam energy of 1.89 GeV were performed in Nov. 2014 and April 2016. The maximum beam-beam parameter reached 0.040 with the bunch current of 8.6mA in Nov. 2014, shown in Fig. 2. The collision bunch current was improved obviously so that the relatively less bunch number could be expected for the high beam current to realize the design luminosity.

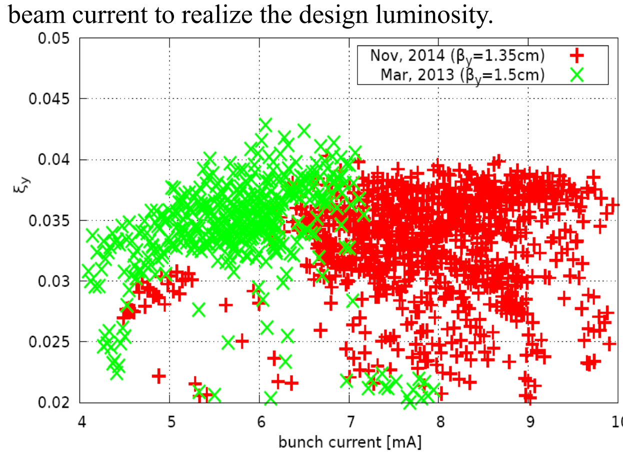

Figure 2: Luminosity for single bunch collision and corresponding beam-beam parameter of the updated lattice.

The stable beam current reached 910 mA with 105 bunches during the commissioning in April 2016. The design luminosity of 1.0×10^{33}cm^{-2}s^{-1} was achieved with the beam current of 849 mA*852 mA on April 5th, 2016. However, the luminosity could not be higher even the beam current was higher than 850 mA because the multi-bunch instability was too strong to be suppressed effectively by the feedback system. The dedicated analysis and the upgrade plan to improve the feedback system have been proposed.

OPERATION WITHIN ENERGY REGION 1.0 GeV TO 2.3 GeV

The operation energy of BEPCII is decided by the BESIII working plan. The operation energy region of BEPCII is from 1.0 to 2.3 GeV. Actually, BEPCII has been operated in this energy region with a full energy injection according to the requirements of high energy physics. The energy region is quite large so that it is very important to select lattice parameters for the optimized luminosity. The energy region was separated into three parts: 1.0 GeV to 1.6 GeV, 1.6 GeV to 1.9 GeV and 1.9 GeV to 2.3 GeV. The horizontal Emittance is the key parameter within the low energy region for the consideration of collision bunch current and bunch number. Bunch length is the key parameter for the high energy region due to voltage limitation of RF cavity. The main lattice parameters for low and high energy regions are shown in Table 4 and Table 5, respectively.

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Table 4: Main Lattice Parameters for Low Energy Region

Parameters	Values
Beam energy	1.0 GeV
β function at IP β_x/β_y	1.0 m/1.2 cm
Horizontal emittance	54 nm·rad
Working point υ_x/υ_y	6.505/5.580
Momentum compaction	0.0286
Natural bunch length	0.6 cm

Table 5: Main Lattice Parameters for High Energy Region

Parameters	Values
Beam energy	2.3 GeV
β function at IP β_x/β_y	1.0 m/1.5 cm
Horizontal emittance	144 nm·rad
Working point υ_x/υ_y	7.505/5.580
Momentum compaction	0.017
Natural bunch length	1.5 cm

During the past years, data taking at 173 high energy points have been finished. The realized peak luminosity at different beam energies are shown in Fig. 3. Red dot means the data taking time is relatively longer.

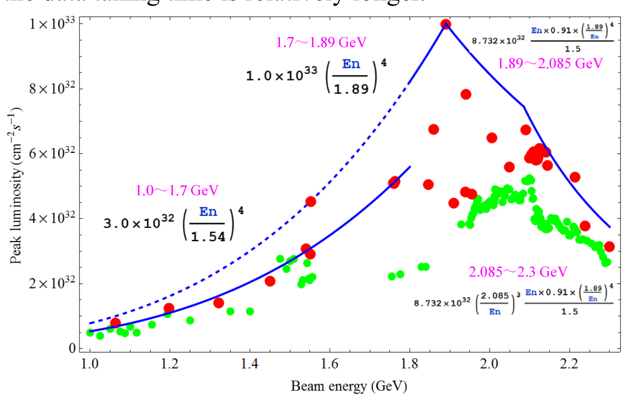

Figure 3: The peak luminosity from 1.0 GeV to 2.3 GeV.

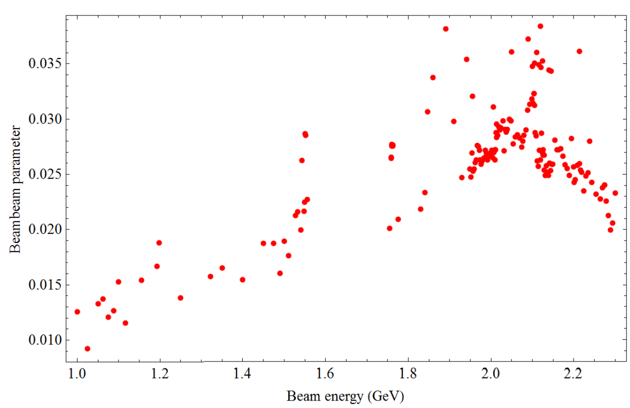

Figure 4: The achieved beam-beam parameter.

The RF system can support a maximum 110 kW beam power. For the operation of high energy region the beam current can't be higher due to the limitation of RF power. Moreover, the bunch length and emittance could not be well controlled so that the beam-beam parameter was lower. For the operation of low energy region the multi-bunch instability was very serious. The beam current was limited by the ability of feedback system. The statistic of beam-beam parameter, beam power, beam current and bunch number are shown in Fig. 4 and Fig. 5.

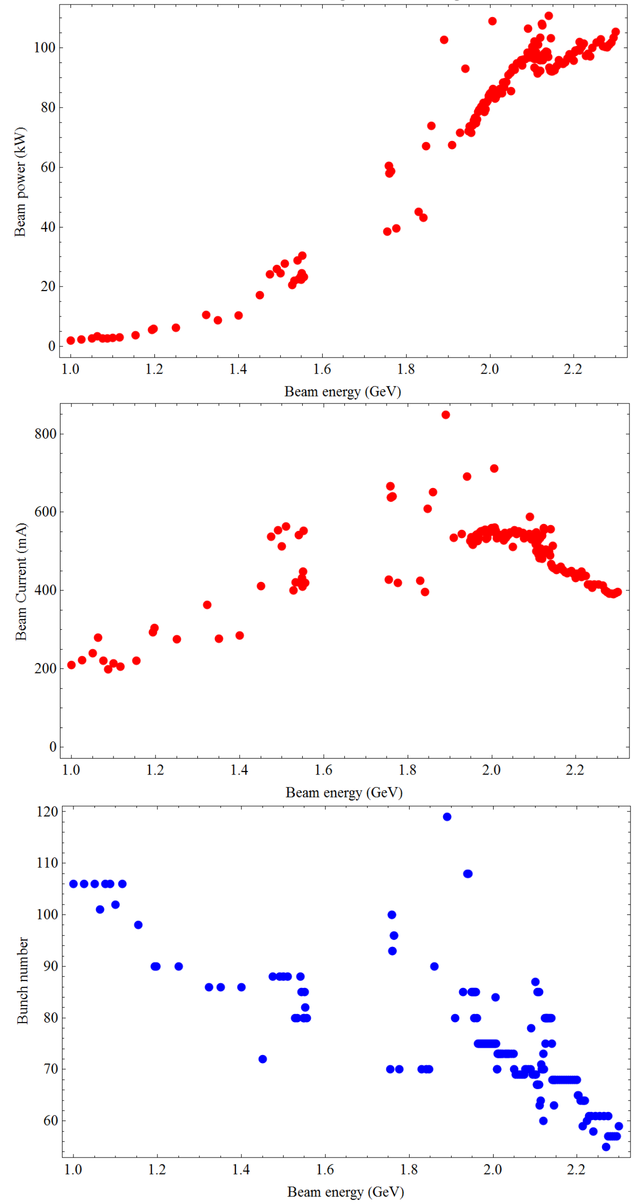

Figure 5: Statistic of beam power, beam current and bunch number.

CONCLUSION

BEPCII is in a good performance for high energy physics with different optics within energy region 1.0~2.3 GeV. The upgrade to take data at the energy 2.3~2.45 GeV is undergoing. The operation with beam energy up to 2.35 GeV is feasible right now. For much higher energy it will be feasible after the summer shutdown of 2019.

REFERENCES

[1] Yuan Zhang *et al.*, in *Proc. IPAC'14*, paper THPRI007.