COMMISSIONING OF BEPCII UPGRADE

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Abstract

The upgrade of Beijing Electron and Positron Collider-II (BEPCII) has begun since the shutdown of BEPCII on July 1st in 2024. The hardware replacement and upgrade has been finished by the end of the year 2024, and the machine commissioning of BEPCII Upgrade project has started since May 2025 after recovery from the cryogenic system fault. The designed luminosity of 1.1×10^{33} cm^{-2}s^{-1} has been achieved on April 28th, 2026. In this paper, we will show the commissioning results of the BEPCII uprade project.

INTRODUCTION

The Beijing Electron Positron Collider II (BEPCII) [1] is a two-ring eletron positron collider running in the tau-charm energy region. The design luminosity of BEPCII has been acheived in 2016 [2] at commissioning mode. Daily operation at designed luminosity has been achieved since Jan. 2023 [3]. The collision energy and data acquisition efficiency upgrade project of BEPCII has been studied since 2019 [4–6], and has begun hardware replacement since July 2024.

BEPCII upgrade is based on the current BEPCII machine, maintaining the existing small Piwinski angle collision scheme unchanged. It increases the collision luminosity at high energies by means of enhancing the beam current and raising the cavity voltage [7–9]. The main logic for parameter selection is to take the synchrotron radiation power of a single beam as the constraint (250 kW) and 120 bunches as the upper limit. At the same cavity voltage, the single-bunch current is kept as low as possible to reduce bunch length stretching and provide the possibility of compressing the vertical β_y^* at the collision point. After selecting β_y^* according to the bunch length, the emittance coupling is determined by the nominal beam-beam parameter $\xi_{y,0}$. The design beam parameters of the upgrade is shown in Table 1.

BEPCII is an operational large scientific facility, and the core purpose of its upgrade is to improve the efficiency of collision, especially in the high-energy region, while attempting and testing the latest accelerator technologies. It can be seen from Table 1 that, the optimized beam energy for the upgrade is 2.35 GeV, and the maximum collision beam energy is extended to 2.8 GeV. The luminosity performance achieved by BEPCII at different energies during its years of operation and the the target luminosity after the upgrade is compared in Fig. 1.

It can be seen that the upgrade will enhance the collision luminosity at beam energies above 2.0 GeV and increase the collision energy up to 2.8 GeV. The luminosity at the optimized beam energy 2.35 GeV can be tripled from 3.5×10^{33} cm^{-2}s^{-1} to 11.0×10^{33} cm^{-2}s^{-1} before and after the upgrade. With this upgrade, the BESIII detector can acquire higher-statistics experimental data in this energy region [10], thereby enabling in-depth exploration of the nature of strong interactions and the origin of hadron masses.

The hardware installation and commissioning of the upgrade project were fully completed in December 2024, followed by a period of cryogenic system failure. After the cryogenic system recovered from the fault, the upgrade project officially entered the beam commissioning phase. This paper provides a comprehensive introduction to the beam commissioning work for the upgrade. The results show that the

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Table 1: Comparison of the design parameters of BEPCII upgrade and the running parameters of BEPCII in collision mode.

Parameters	BEPCII	BEPCII upgrade	
Energy [GeV]	2.35	2.35	2.8
RF voltage [MV]	1.6	1.65× 2	1.65× 2
SR power [kW]	110	250	250
Damping time [ms]	12.6	12.6	7.5
Bunch number	56	120	36
Bunch current [mA]	7.1	7.5	12.5
β_x^*/β_y^* [m]	1.0/0.015	1.0/0.0135	1.0/0.03
Emittance [nm·rad]	147	152	200
Coupling [%]	0.53	0.35	0.5
$\xi_{y,lum}$	0.029	0.033	0.043
ν_s	0.027	0.04	0.035
Bucket height	0.0069	0.011	0.009
$\sigma_{z,0}$ [cm]	1.54	1.01	1.40
σ_z [cm]	1.69	1.22	1.60
Peak luminosity 10^{32}cm^{-2}s^{-1}	3.5	11	3.7

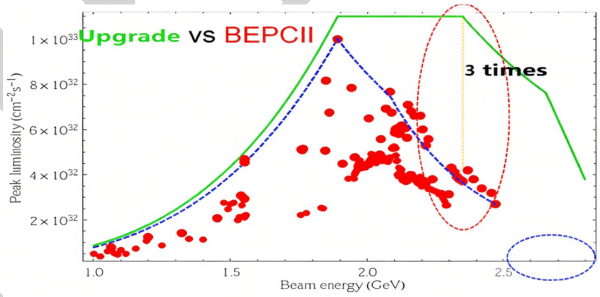

Figure 1: comparison of the luminosity performance achieved by BEPCII at different energies during its operational years and the target luminosity after the upgrade..

Figure 2: The measured horizontal and vertical BPM offsets at BPR and BER.

optics and beam parameters have been well tuned. The designed peak luminosity has been achieved at a lower beam current, thanks to the higher beam-beam parameter. The achievement of the peak luminosity indicates that the upgrade of BEPCII has been successfully completed.

COMMISSIONING OF THE UPGRADE

The first commissioning run started with a beam energy of 1.843 GeV to calibrate the BESIII system. It was found that the beam energies of BER and BPR at 1.843 GeV were asymmetric, and the maximum closed orbit deviation (COD) around the two rings reached up to 10 mm. Therefore, before ramping up the beam energy to 2.35 GeV, we first corrected the horizontal beam orbit to the minimum possible level and simultaneously adjusted the energies of the two rings to be symmetric. Full-ring vertical closed orbit correction was also performed to minimize the deviation. It was found that the COD correction was highly effective in reducing transverse couplings and optimizing the peak collision luminosity. Starting from February 26, 2026, BEPCII increased the beam energy to 2.35 GeV, which is the optimal beam energy for the upgrade.

The BPM offsets were measured for both BER and BPR rings. The measurement results of BPM offset are shown in Fig. 2. It is shown that, the horizontal and vertical offset values of each BPM (including BER, BPR) were measured systematically, with most offset values fluctuating around 0 mm and within the range of −5 mm to +5 mm. Among these, the horizontal offset of R2IBPM16 reached −19.4608 mm and its vertical offset was −12.0586 mm, which were the most significant deviations. Additionally, the horizontal offsets of R1OBPM12 and R4IBPM00 were −17.11 mm and −16.8 mm, respectively, exhibiting large deviations in the horizontal direction. These BPMs with abnormal large offsets will be excluded during optics and coupling correction.

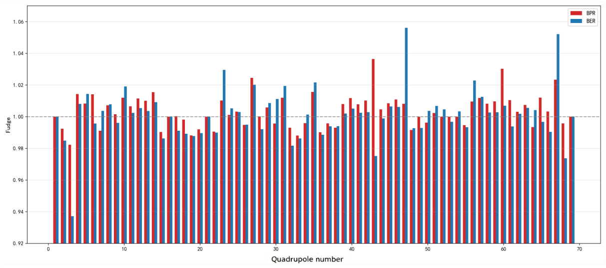

Figure 3: The fudge factors for normal-temperature quadrupoles in BPR and BER.

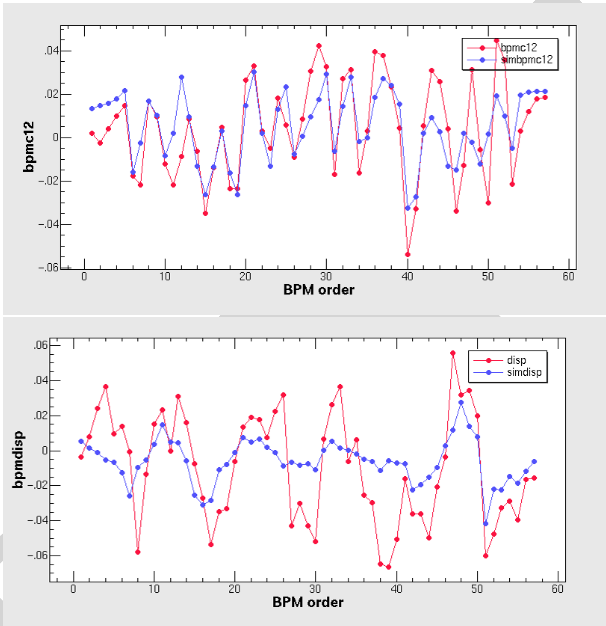

Figure 4: The measured and simulated coupling factor C12 and vertical dispersion distribution in BER.

The online lattice was corrected using the response matrix method. The strengths of all quadrupoles except the Superconducting Quadrupole (SCQ) were corrected by applying a fudge factor to their nominal values. In contrast, the strength of the SCQ was scaled in accordance with the factor used in BEPCII. The distribution of fudge factors for all normal-temperature quadrupoles in both the BPR and BER rings is shown in Fig. 3. It can be seen form Fig. 3 that, the fudge factors of most normal-temperature quadrupoles deviate from their nominal values within ±2%, which is consistent with the design requirements. A small number of quadrupoles have slightly larger deviations, but all are within the acceptable range for beam operation. The beta beating amplitude after correction is about ±2% for both BPR and BER rings.

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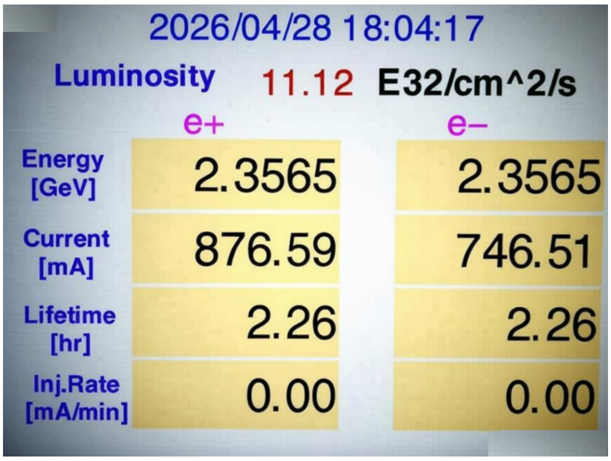

Figure 5: The achieved peak luminosity.

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Reducing the coupling between the transverse planes is of great importance for reducing the vertical emittance and thus the vertical beam size, thereby increasing the collision luminosity. The coupling correction in BEPCII is performed in two steps. First, the global coupling factor is analytically minimized using the 8 skewed quadrupoles and vertical correctors distributed around the ring; then, the local coupling parameters (R1, R2, R3, R4, η_y and η_y') at the interaction point (IP) are manually adjusted to maximize the collision luminosity. Additionally, the vertical orbit at the sextupoles with the maximum strength in each arc region is manually tuned to optimize the collision luminosity. The typically measured and calculated distributed coupling factors $C12$ and η_y at each BPM [11] for the BER are shown in Fig. 4.

It is seen from Fig. 4 that the measured distributed coupling factor $C12$ at each BPM oscillates around 0, within the range of ±0.04. The calculated distributed coupling factor using the optics model is in good agreement with the measurement results. The measured vertical dispersion function η_y at each BPM also oscillates around 0, within the range of ±0.06 m. Although the oscillation trends of the measured and calculated η_y are consistent, their absolute values differ. This discrepancy may arise from measurement errors, as the detuning of the RF frequency is limited and the vertical dispersion value itself is small.

After rounds of optimization, the designed luminosity of 1.1×10^{33} cm^{-2}s^{-1} was achieved on April 28, 2026. The detailed beam parameters at the time of achieving the designed luminosity are shown in Fig. 5. The designed peak luminosity was achieved at a lower beam current than the designed value, thanks to the higher beam-beam parameter of 0.036, which is 10% higher than the target value.

SUMMARY

In this paper, we presented the commissing results of the BEPCII upgrade.The results show that the optics and beam parameters have been well tuned. The designed peak luminosity has been achieved at a lower beam current, thanks to the higher beam-beam parameter. The achievement of the peak luminosity indicates that the upgrade of BEPCII has been successfully completed.

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