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RECENT PROGRESS OF THE BEAM BACKGROUND EXPERIMENT IN THE BEPCII*

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Abstract

The Beijing Electron Positron Collider II will upgrade to extend the beam energy and the luminosity by increasing the beam current and slightly compressing the beam size, where the beam energy will be extended from 2.3 GeV to 2.8 GeV and the peak luminosity will be up to $1.1 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at the optimizing beam energy of 2.35 GeV. The BEPCII upgrade is expected to result in challenging levels of beam related background in the interaction region. An precise simulating and mitigating beam background is necessary to protect the BESIII detector and increase the beam current and peak luminosity. The beam related background at BEPCII is mainly from the Touschek effect and the beam gas effect, this paper presents the recent progress of the beam background simulation and experiment.

INTRODUCTION

The Beijing Electron Positron Collider II (BEPCII) [1] is a two-ring electron positron collider which has operated successfully for over 10 years and collected more than 40 fb^{-1} data sets in the τ-charm energy range. A series of significant experimental observations have been reported based on these data sets [2]. In 2019, BESIII collaboration has reported the future physics programme (also called "white paper") which contains a detailed survey of important topics in τ-charm physics and hadron physics [3]. However, the age of BEPCII becomes an important issue, such as main drift chamber (MDC). Due to the beam-induced with a hit rate up to 2 kHz/cm^2, the cell gains of the inner chamber drops dramatically (about 39% drop for the first layer cells in 2017) and furthermore lead to a degradation of the spatial resolution and reconstruction efficiency [3]. In addition, the peak luminosity of BEPCII is optimized at 1.89 GeV, the evaluated peak luminosity at 2.35 GeV is only $0.35\times10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Therefore, an upgrade is required for BEPCII to collect more data sets in this energy region, espectially at center-of-mass energies larger than 4 GeV [4]. The peaking luminosity at 2.35 GeV will increase to $1.1\times10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ with high beam current and small beam size. However, the resulting high beam background must be controlled within a safe range.

In the beginning of BEPCII, ten collimators with fixed aperture were installed on both the electron and positron rings. Three horizontal movable collimators were installed at 8.2 m, 11 m upstream, and 11 m downstream from IP on the electron ring , and a horizontal movable collimator was installed at 8.2 m upstream from IP on the positron ring. Simulations of beam-gas effect [5], Touschek effect [6], SR [7] and movable collimators [8] were separately studied to predict the background rate in BESIII. These collimators obviously mitigated the beam background and played an important role in the stable operation of the BEPCII machine in its initial stage. Each movable collimator has a pair of movable jaws which is able to adjust their aperture independently. Due to the high beam current and small beam size of BEPCII upgrade project, it is necessary to rexamine beam background simulation and experiments.

BEAM BACKGROUND SIMULATION AND EXPERIMENT IN 2021

The beam background at BEPCII consists of luminosity-related background and beam-related background, where the first one is generated by beam-beam interaction and can be simulated with an acceptable precise, the second one is highly dependent on beam parameters and the storage ring. The dominant sources of beam-related background can be parameterized by:

$$O_{\mathrm{SingleBeam}} = S_{\mathrm{tous}} \cdot \frac{I_t \cdot I_b}{\sigma_x\sigma_y\sigma_z} + S_{\mathrm{gas}} \cdot I_t \cdot P(I_t) + S_{\mathrm{const}}, \quad (1)$$

where $O_{\mathrm{SingleBeam}}$ is the total background rate of single beam and can be described by the dark current or count rate of the machine-detector interface (MDI). The first term (the Touschek background) is proportional to bunch current (I_b) and beam current (I_t), and inversely proportional to beam size ($\sigma_{x,y,z}$). The second term (beam-gas background) is proportional to beam current and vacuum pressure. Generally, the residual gas mainly comes from the interactions between synchrotron radiation (SR) photons and the inner wall of beam pipe, so the vacuum pressure depends on the beam current. The third term is the constant background from cosmic rays and electronic noise, independent of the beam condition and can be presented by a constant term.

The beam-related background simulation is based on the framework which includes generators for lost particles, SAD [9] for tracking the particles in the collider ring, and Geant4 [10] and Geant4-based software framework of the BESIII offline software system (BOSS) [11] for simulating the detector's responses and MDI. The beam background experiment was performed for validating the simulation result. The "data/MC" ratio, which is the ratios of the background

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rate between experimental measurements and simulating prediction, is used to evaluate the difference between them.

We performed a separate measurement of the main two beam-related beam background components in 2021. Figure 1 shows the distribution of the count rate in the first layer of the MDC versus the bunch current for both electron and positron beams, where the nominal total beam current is set to 450 mA, the bunch current and bunch number are scanned from 3.8 mA to 8 mA and 118 to 56, respectively. According to Eq. 1, the Touschek background is calculated from the slope in the linear fit and the intercept of the fit denotes the beam-gas and constant background. Figure 2 shows the separated beam background in all layers of the MDC. The results show that the Touschek background is dominant in all layers, and the beam-gas consitutes a small portion, especially in the outer layers. Figure 3 shows the "data/MC" ratios of the background rate between experiments and MC simulations, the result reveals that the simulating Touschek background is larger than that in the experimental measurement by one to two orders of magnitude. It means that more optimizations for simulation and experiment, such as collimator simulation, particle tracking, and the interactions of MDI materials in simulation, are necessary for future work.

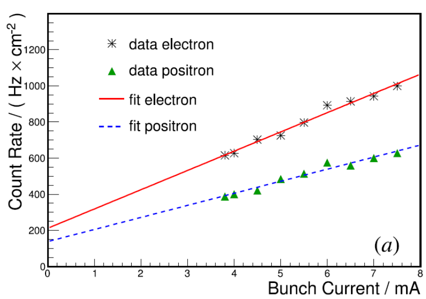

Figure 1: The distribution of the count rate in the first layer of the MDC with respect to the bunch current for both electron and positron beams, where the beam current is set to 450 mA.

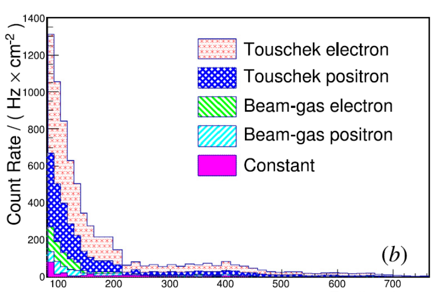

Figure 2: The distribution of the accumulated count rate of separate background sources in all MDC layers, where the bunch current is set to 6 mA.

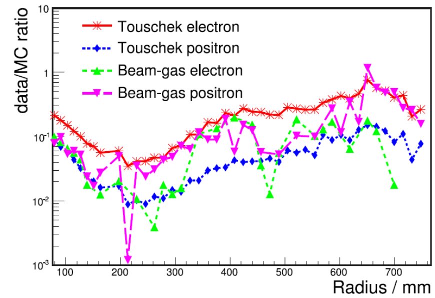

Figure 3: Data/MC ratios with respect to the radius of all MDC layers for both electron and positron beams for the Touschek and beam-gas effects.

MOVABLE COLLIMATOR EXPERIMENT IN 2022 AND 2023

We have conducted several tests on these movable collimators in the last decade. Changing the aperture of these collimators will increase the vacuum pressure and worsen the operation status. So it is necessary to perform a feasibility test for changing the aperture of these collimators. In 2022, we perform the feasibility experiment and irradiation dose of these collimators. The results show that changing the aperture of collimatos can suddenly but no dramatically increase the vacuum pressure and decrease the lifetime of beam. While the vacuum pressure and lifetime will recoverd in a few seconds. It indicats that more detailed collimator experiments can be conducted in the next beam background experiment.

The following movable collimator experiment is conducted in 2023:

1. Baseline beam background experiment. To compare with the experiment results collected in 2021, a series of baseline beam background experiment is performed for different aperture of these movable collimators,We also set the nominal single beam current to 450 mA and four bunch number, which are 60, 75, 82, and 90.
2. Aperture scan. We independently scan the aperture of the inner and outer jaw for all four movablbe collimators on both electron and positron ring. The aperture settings with minimul dark current are assumed to be the "best settings" for further beam background experiment.
3. Baseline beam background experiment with best seetings of movable collimators.
4. Beam background experiment with different aperture settings. We collect the experimental data by changing the aperture of each movable collimators.
5. Beam background experiment with different beam current.

Figure 4 shows the overall plots for the beam backgorund experiment in 2023. 01 to 17 denotes the different experiment item, where 01 and 11 denote the baseline beam background experiment before collimator movements for electron

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and positron rings, respectively. 02 and 03 denote the aperture scan of the outer and inner jaw of the movable collimator at 8.2 m upstream from IP on the electron ring. 04 and 05 denote the aperture scan of the outer and inner jaw of the movable collimator at 11.0 m upstream from IP on the electron ring. 06 and 07 denote the aperture scan of the outer and inner jaw of the movable collimator at 8.2 m downstream from IP on the electron ring. 08 and 14 denote the baseline beam background experiment with the best settings of the movable collimator movements on the electron ring, 09 and 15 denote the beam background experiment with different aperture settings for electron and positron rings, respectively. 10 and 16 denote the beam background experiment with different beam current. 12 and 13 denote the aperture scan of the outer and inner jaw of the movable collimator at 8.2 m upstream from IP on the positron ring. 17 denotes the normal data taking with the best settings of all movable collimator movements.

The further data analysis is ongoing. The preliminary result shows that the movable collimator upstream from IP obviously effect the beam background, while the collimator downstream from IP has not obvisouly effect the beam background. The collimator in positron ring is much more effective than that of electrion ring. It is worth noting that the beam lifetimes and the luminosities for different aperture settings are almost unchanged. We also perform an additional validation for the best setings of these movable cllimator in the normal collider, which the beam current is up to 900 mA. By comparing the dark current with and without the best seetings of these movable collimator, the dark current is decreased from 11 µA to 6 µA (about 40%). This obvious decrease of the beam background will provide a important support for the top-up injection in the next machine runing, as well as the beam background evaluation of the BEPCII upgrade project.

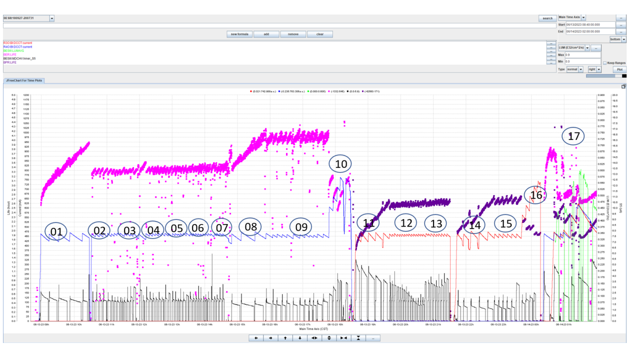

Figure 4: The beam background experiment in 2023, where the pink and purple points are the lifetime of electron beam and positron beam, respectively. the green, black, red and blue curve are the peak luminosity, dark current, electron beam current, positron beam current, respectively.

CONCLUSION

In summary, we reported the recent progress of beam background experiments and simulations at BEPCII. The Touschek background is dominant in the beam-related background according to results of experiment and simulation. A comparison between experiment and simulation for Touschek background shows a discrepancy of one to two orders of magnitude. A series of movable collimators experiment is conducted. The collimator at downstream from IP is expected to be no significant effect with the beam background, while the collimator at 8.2 m upstream from IP obviously effect the beam background. The best settings of the aperture of all collimators is calculated and obviously mitigated the beam background. Further data analysis for these data sets is necessary for comparing with the simulating result and evaluating the beam background for the BEPCII upgrade project. An additional data taking with the best setting of these movable collimators is perfromed, the dark current is decreased from 11 µA to 6 µA (about 40%) with 900 mA beam current and the beam lifetime and peak luminosity are no obviously changed. The obvious mitigation of beam background will play an important role of the future data taking of BEPCII and the evaluation of the beam background of the BEPCII upgrade.

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