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# Application of movable collimators to the BEPCⅡ *

LUO Tao(罗涛)[1,2;1)] JIN Da-Peng(金大鹏)[1;2)] XING Jun(邢军)[1] HUANG Nan(黄楠)[1]
DONG Ming-Yi(董明义)[1] LI Wei-Guo(李卫国)[1] LI Hai-Bo(李海波)[1]
WU Ying-Zhi(吴英志)[1] ZHANG Qing-Jiang(张清江)[1] LIU Guan-Chuan(刘冠川)[1,2]

[1] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China
[2] Graduate University of Chinese Academy of Sciences, Beijing 100049, China

**Abstract** BEPCⅡ is a double ring $e^+e^-$ collider with high beam currents and luminosity, so the high beam-related backgrounds may disturb the detector. In order to have a good quality of data taking, backgrounds should be kept at a level as low as possible. A series of collimators are designed and installed in both the $e^+$ and $e^-$ rings. Two of the collimators are horizontally movable, each for one ring, about 8 m upstream from the interaction point. Experiments have been done to identify the effectiveness of the movable collimators with different apertures and beam currents. The results show that the movable collimators are very effective and can reduce as much as about 50% of beam-related backgrounds.

**Key words** movable collimators, beam-related backgrounds, dark current

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## 1 Introduction

The new generation Beijing electron-positron collider (BEPCⅡ) and its detector system Beijing Spectrometer (BESⅢ) [1] have been built successfully. After the commissioning of the BEPCⅡ, the beam currents go higher and higher towards the designed values. As a consequence, the higher and higher beam-related backgrounds may disturb the BESⅢ, especially the inner most detector Main Drift Chamber (MDC).

The MDC is the most important and unique tracking sub-detector at the BESⅢ experiment. It is used to precisely determine the track momentum, direction and vertex position of charged particles. The MDC is composed of an inner chamber without an outer wall and an outer chamber without an inner wall, which are jointed by 6 stepped end flanges [1]. There are altogether 43 sense wire layers in the MDC, in which 8 layers are in the inner part and 35 layers in the outer part. The inner radius of the inner chamber is 59 mm and the outer radius of the outer chamber is 810 mm. The length of inner chamber and outer chamber are 844 mm and 2308 mm, respectively. It is symmetrical in the $z$ direction to cover the polar angle region of $-0.93 \leqslant \cos\theta \leqslant 0.93$. To precisely determine the polar angle of tracks, wires in the inner chamber are designed to be stereo. In the outer chamber, there are in total 16 stereo and 19 axial layers. A small cell structure is chosen with a nearly square shape in $r$-$\phi$ plane and the sense wire is located in the center and surrounded by 8 (or 9) field wires. The average half cell width is 6 mm in the inner chamber and 8.1 mm in the outer one. A helium based gas mixture (He(60%)+$C_3H_8$(40%)) is chosen to minimize the effect of multiply scattering while maintaining a reasonable $\mathrm{d}E/\mathrm{d}x$ resolution. The designed single wire spatial and $\mathrm{d}E/\mathrm{d}x$ resolution are 130 μm and 6%, respectively.

There are several sources of beam-related backgrounds [2], including the synchrotron radiation photons [3], the beam-gas [4] and Touschek [5] lost particles. Detailed simulations have been done during the construction of the BEPCⅡ/BESⅢ. Results from the simulations show that it is necessary to install collimators on the storage ring to prevent beam-gas

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1) E-mail: luot@mail.ihep.ac.cn

2) E-mail: jindp@mail.ihep.ac.cn

and Touschek lost particles from hitting the interaction region and a series of collimators are designed and installed in both the $e^+$ and $e^-$ rings. The physical aperture about 2 m upstream from the Interaction point (IP) near the crotch pipe is about $14\sigma_x$, which is the bottleneck in the interaction region, so two horizontally movable collimators are installed about 8 m upstream from the IP to reduce the number of lost particles near the crotch pipe, and to minimize the detector backgrounds, each for one ring.

Touschek backgrounds are not easy to model since they relate closely to the operation mode of the accelerator, the local beam sizes, the radio frequency acceptance and so on. Comparison between the simulations and the experiments is based on the beam-gas induced backgrounds.

In this paper, the effectiveness of the movable collimators are described based on the behavior of the MDC in response to the aperture changes.

## 2 Beam-related background experiments in the BEPCⅡ/BESⅢ

On December 5, 2008 and February 13, 2009, experiments were carried out to verify the effectiveness of the movable collimators. The inner four layers of the MDC are used to measure the effectiveness since they suffer the most serious beam-related backgrounds. Dark currents are taken as the reference since they are nearly proportional to the rate of charge deposited onto the wires.

### 2.1 High voltage supply and experimental content

The inner four layers of the MDC are divided into sections, as shown in Fig. 1, each with an individual high voltage (HV) supply. The space coordinate is defined as $+X$ points horizontally to north– the inner ring, $+Y$ points up vertically and $+Z$ points to east– along the positron beam. There are movable collimators (8.2 m upstream from the IP) in the electron ring and positron ring whose half apertures can be changed between 42 mm (opened) and 26 mm (closed) in the horizontal directions. These collimators are made of oxygen-free copper and the smallest apertures of them are $12\sigma_x$ ($\sigma_x$ is the beam size in the $x$ direction).

### 2.2 Results of the experiment

In order to reduce the beam-related backgrounds as dramatically as possible and find the best aperture of the collimators, we designed the following experiments.

#### 2.2.1 Beam-related background experiment for the $e^+$ beam

In this experiment, the total current of the $e^+$ beam is kept to about 150 mA, while the single bunch current is changed between 1 mA and 6 mA. The movable collimators in the positron ring are opened and closed in turn and the dark current in every HV channel of the inner 4 layers in the MDC is recorded.

Figure 2 shows the curve of the dark current changes in the MDC 1st layer with a bunch current of 1 mA, and Fig. 3 shows the same distributions in the MDC 2nd layer. Horizontal collimators are opened at data points 1 and 4, and closed at data points 2 and 3. From Figs. 2 and 3, it can be seen clearly that the dark currents of the MDC inner layers decrease dramatically with the collimators closed. Fig. 4 shows the curve of the dark current changes in the MDC 1st layer with a bunch current of 6 mA. Fig. 5 shows the same distributions in the MDC 2nd layer. Horizontal collimators are opened at data points 5 and 8, and closed at data points 6 and 7. The collimators are very effective. Compared with Figs. 2 and 3, the collimators are much more effective with a bunch current of 6 mA than that of 1 mA.

The changing ratios of dark currents of the MDC 1st layer are calculated using two data points in Figs. 2 and 4 with different collimator apertures. Adjacent points are used in the calculations since the total beam current remains almost constant. Fig. 6(a) shows the dark current changing ratios of each high voltage channel in the MDC 1st layer between points 1 and 2 in Fig. 2. Fig. 6(b) shows the changing ratios between points 3 and 4 in Fig. 2. Fig. 6(c) shows the changing ratios between points 5 and 6 in Fig. 4. Fig. 6(d) shows the changing ratios between points 7 and 8 in Fig. 4.

When the collimators are closed from opening, the changing ratio of dark currents of the 1st layer of the MDC is about 33% and 23% on average for a bunch current of 6 mA and 1 mA, respectively. The effectiveness of the collimators (the changing ratio of dark currents of the 1st layer of the MDC) for the case of a 6 mA single bunch current is 10% larger than that of a 1mA single bunch current.

#### 2.2.2 Beam-related background experiment for $e^-$ beam

The experiment of the $e^-$ beam is similar to that of the $e^+$ beam.

The curves of the dark current change in the MDC 1st layer with a bunch current of 1 mA, shown in Fig. 7 and the same curves in the 2nd layer are

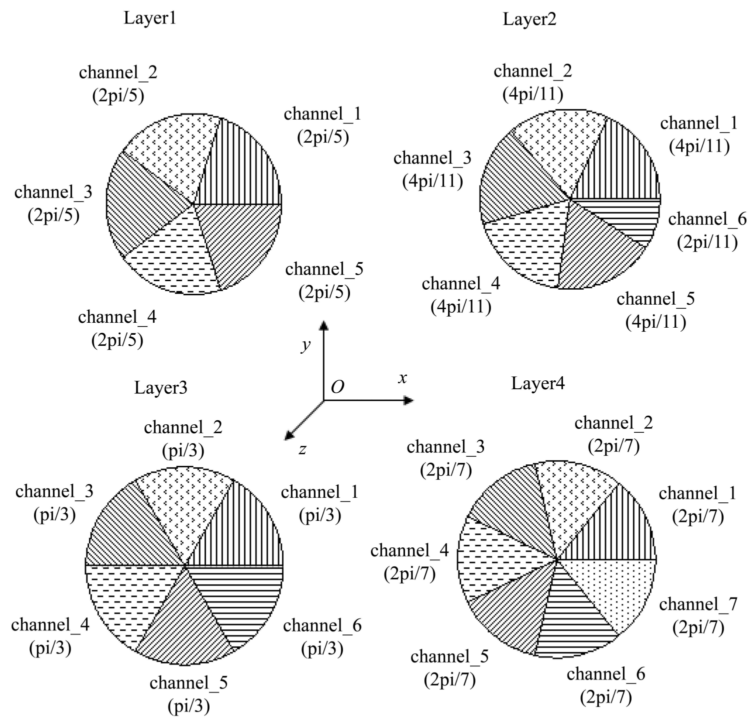


Fig. 1. The high voltage channels of the inner 4 layers in the MDC.

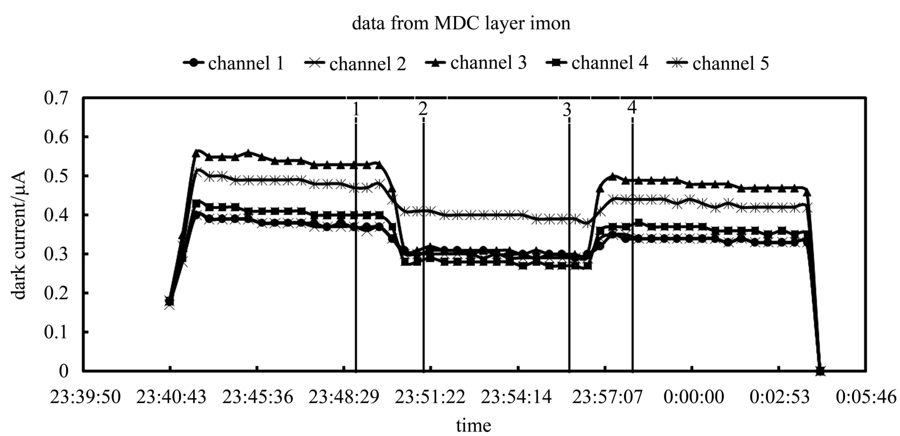


Fig. 2. The curve of the dark current variation in the MDC 1st layer (1 mA/b $e^+$ beam).

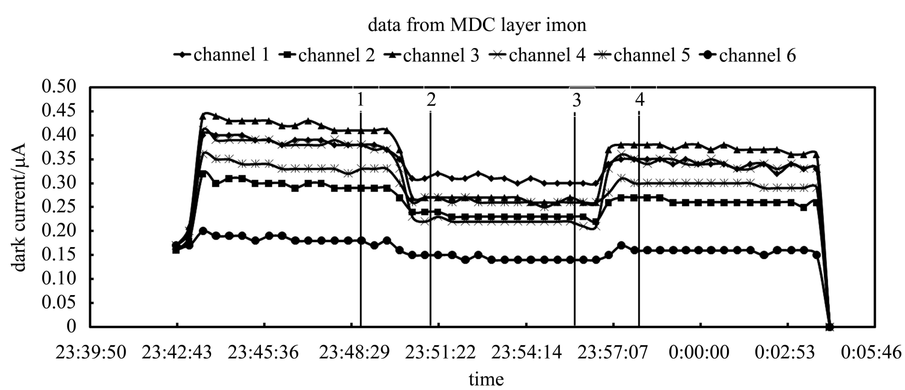


Fig. 3. The curve of the dark current variation in the MDC 2nd layer (1 mA/b $e^+$ beam).

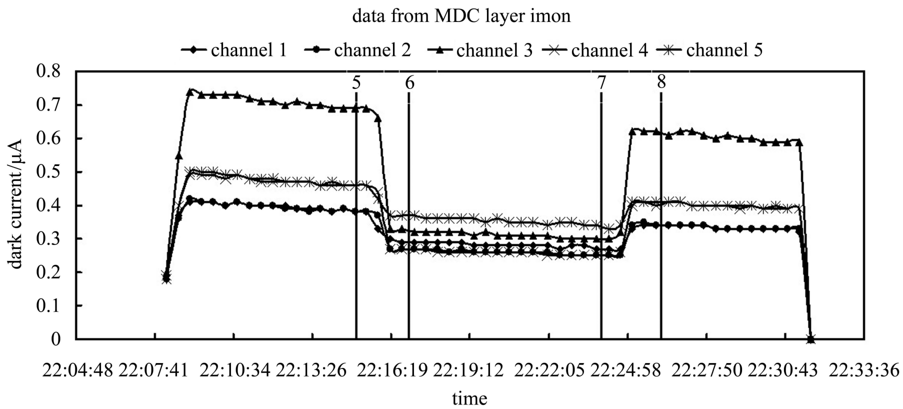


Fig. 4. The curve of the dark current variation in the MDC 1st layer (6 mA/b $e^+$ beam).

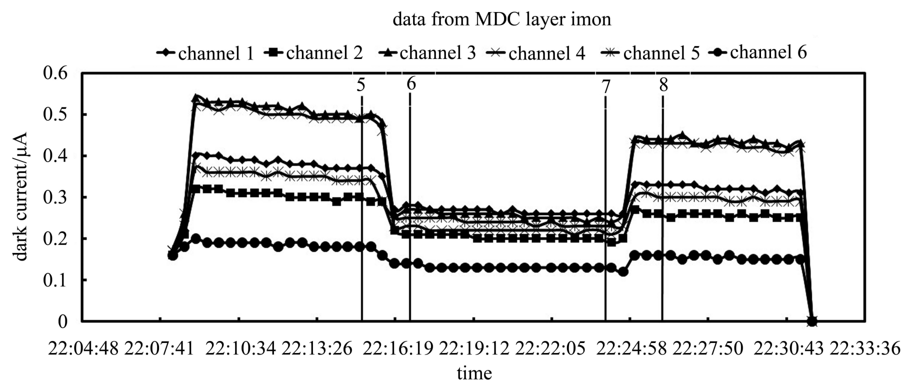


Fig. 5. The curve of the dark current variation in the MDC 2nd layer (6 mA/b $e^+$ beam).

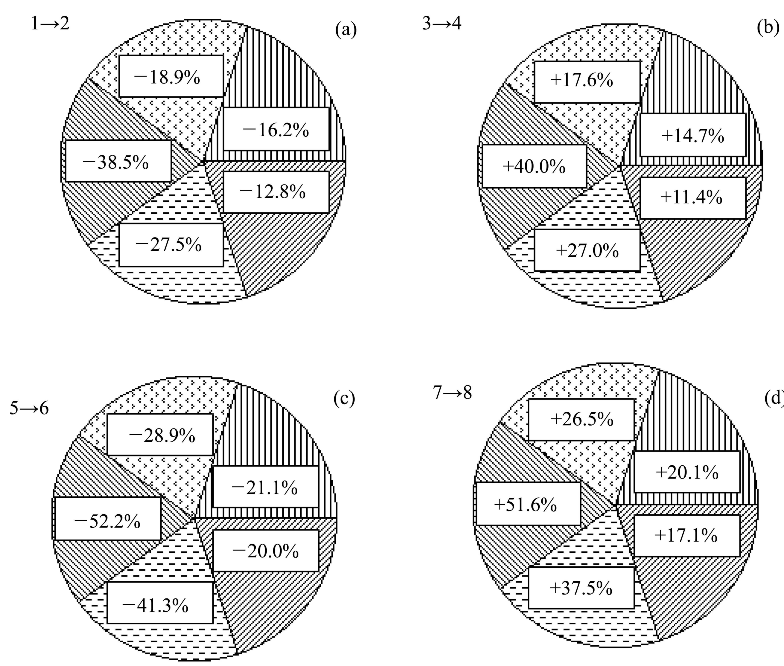


Fig. 6. Changes of dark current in the MDC 1st layer ($e^+$ beam).

displayed in Fig. 8. Fig. 9 and 10, showing the curves of the dark current changes in the MDC 1st layer and 2nd layer, respectively, with a bunch current of 6 mA. Horizontal collimators are opened at data points 1 and 4, and closed at data points 2 and 3.

The changing ratios of dark currents in the MDC layer 1st and layer 2nd are calculated using two data points in Figs. 7 and 9 with different collimator apertures. Figs. 11(a) and 11(b) show the changing ratios of each high voltage channel in the MDC first layer and second layer between data points 1 and 2 in Fig. 7. Figs. 11(c) and 11(d) show the changing ratios of each high voltage channel in the MDC first layer and second layer between data points 3 and 4 in Fig. 9. From these results, it can be found that the changes in dark current caused by movable collimators in the horizontal directions are larger than those in the vertical directions. For the $e^-$ beam, when the collimators are closed from opening, the changing ratio of the dark currents of the 1st layer of the MDC is about 51.5% and 37% on average for a bunch current of 6mA and 1mA, respectively. The effectiveness of the collimators (the changing ratio of dark currents of the 1st layer of the MDC) for the case of a 6 mA single bunch current is 14.5% larger than that of a 1mA single bunch current.

Comparing Figs. 2 and 4 with Figs. 7 and 9, it can be found that the movable collimators in the electron ring are much more effective than those in the positron ring.

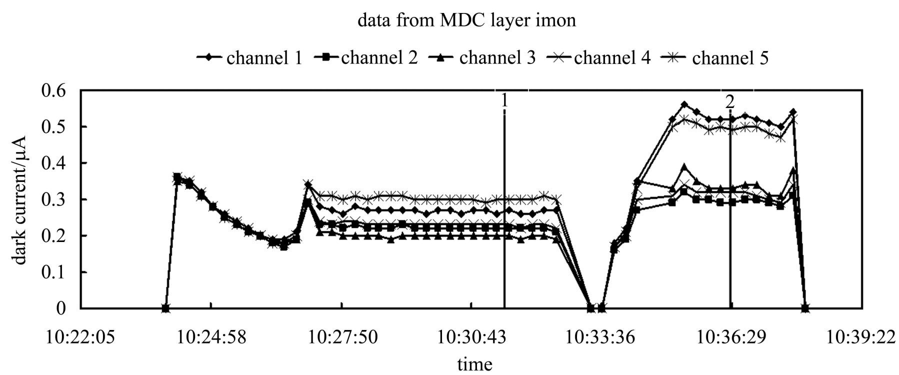


Fig. 7. The curve of the dark current variation in the MDC 1st layer (1 mA/b $e^-$ beam).

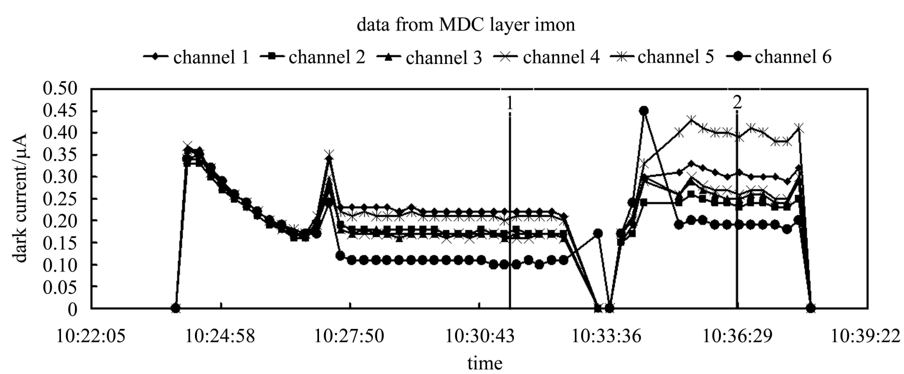


Fig. 8. The curve of the dark current variation in the MDC 2nd layer (1 mA/b $e^-$ beam).

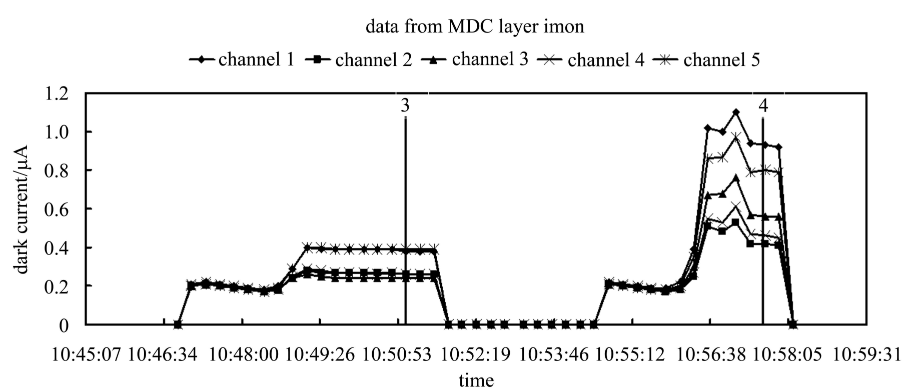


Fig. 9. The curve of the dark current variation in the MDC 1st layer (6 mA/b $e^-$ beam).

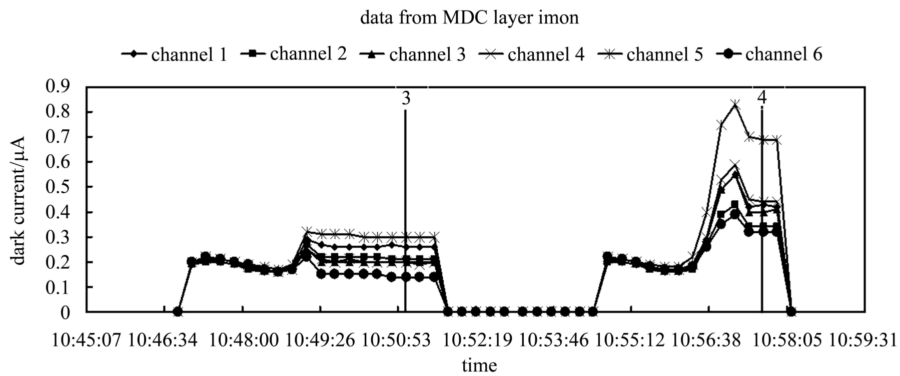


Fig. 10. The curve of the dark current variation in the MDC 2nd layer (6 mA/b $e^-$ beam).

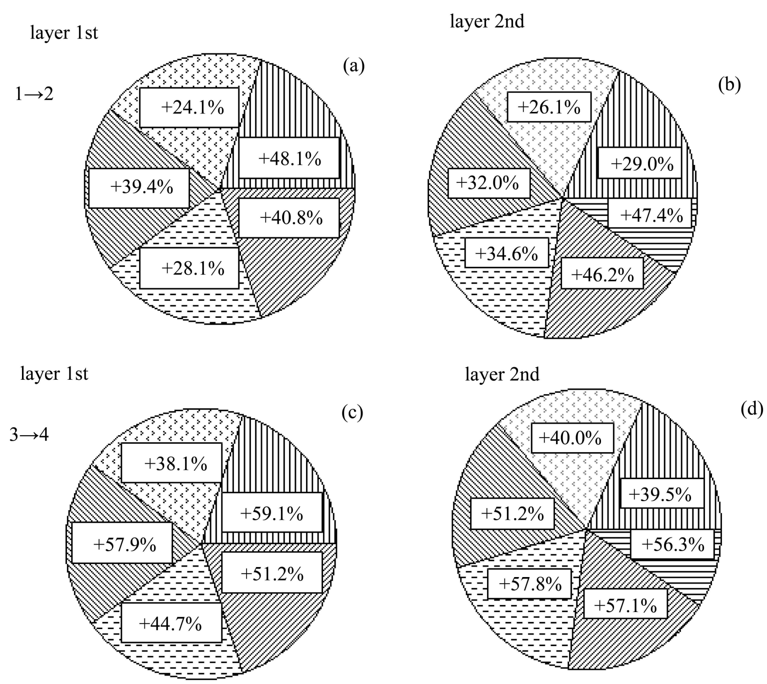


Fig. 11. Changes in dark current in the MDC 1st layer and 2nd layer ($e^-$ beam).

## 3 Comparison between experiment and Monte Carlo Simulation

Synchrotron radiation photons mainly affect the inner most layers of the MDC, especially the 1st layer, since their lower energies, backgrounds in the MDC are mainly from beam-gas interactions and Touschek effects, except or besides the 1st layer.

For the Touschek effects, the rate of lost particles is proportional to the square of the bunch current for a single bunch with fixed beam sizes [5]. For multi-bunches with the same bunch current, the rate of lost particles is proportional to $N_B \times I_B^2$, where $N_B$ is the number of bunches and $I_B$ is the single bunch current.

In the case of this paper, the ratio of the 6 mA bunch current to that of the 1 mA bunch current from the Touschek background is $25\times6^2/(150\times1^2)=6$.

The 2nd layer in the MDC is used to estimate the portion of backgrounds from beam-gas interactions and Touschek effects to avoid impact from synchrotron radiation photons. Assuming that beam-gas backgrounds are proportional to total beam current [4] and all backgrounds are from beam-gas interactions and Touschek effects, then one gets

$$I_{\rm dGas} + I_{\rm dTou} = 1.04\ \mu\text{A}, \tag{1}$$

$$I_{\rm dGas} + \tilde{I}_{\rm dTou} = 1.31\ \mu\text{A}, \tag{2}$$

where $I_{\rm dGas}$ is the dark current in the layer 2nd in the MDC caused by beam-gas interactions with a total beam current of 150 mA, $I_{\rm dTou}$ and $\tilde{I}_{\rm dTou}$ are the dark currents in the layer 2nd of the MDC caused by Touschek effects with a single bunch current of 1 mA and 6 mA, respectively. Similarly, the two values of 1.04 μA and 1.31 μA are the total dark currents in the 2nd layer of the MDC with a single bunch current of 1 mA and 6 mA, respectively, which is obtained from the slow control database. We have the following relation for single bunch current between 6 mA and 1 mA:

$$\tilde{I}_{\rm dTou} = 6 \times I_{\rm dTou}. \quad (3)$$

Settling the equations above, one gets $I_{\rm dGas}$= 0.986 μA, $I_{\rm dTou}$=0.054 μA, $I_{\rm dTou}/(I_{\rm dGas}+I_{\rm dTou})$ = 5.2%, so the beam backgrounds are almost all from beam-gas interactions for the case of a single bunch current of 1 mA.

According to reference [2], the beam-gas backgrounds are mainly from the upper ring of the beam within 40 m from the IP for the BEPC/BESⅡ case. The same assumption can be made since the BEPCⅡ/BESⅢ uses the same tunnel and experimental hall as the BEPC/BESⅡ.

In the BEPCⅡ case, for the upper ring within 40 m from the IP, two horizontal collimators are set. One is fixed about 28 m from the IP and the other is movable about 8 m from the IP with adjustable apertures. Since there is only a distance of 12 m at the far end of the IP for the fixed collimator to reduce the backgrounds, we assume that the movable one has full effectiveness for the beam-gas induced particles. Then, a comparison between the experimental data for the case of a 1 mA single bunch current and Monte Carlo simulations can be carried out.

Assuming that the energy rate lost near the IP is proportional to the rate of charge on the wires. From table 3 in the paper [4], the energy rate lost in the region within 5 m from the IP by beam-gas interactions is about 2525 MeV/μs and 5251 MeV/μs, respectively, for the cases with and without the collimators on the storage ring, so the effectiveness of the collimators in the Monte Carlo simulations is about 52%. While the experiment gives out an effectiveness of about 40% for the case of a 1 mA single bunch current. The two results are consistent in general for relative effectiveness.

## 4 Summary

Beam-gas lost particles contribute a relatively large portion to the detector backgrounds, vacuum in the storage ring within several tens of meters upstream from the IP needs to be improved to reduce the backgrounds, especially in the case of high beam current with poor dynamic vacuum. The physical aperture about 2 m upstream from the IP near the crotch pipe is not enough, even though the absolute aperture of the super-conducting quadrupole is the maximum one within the same kind of magnets in the world. The relatively short circumference of the storage ring and linear region near the interaction point restricts the optimization of the accelerator between luminosity and beam-related backgrounds.

Collimators including the two horizontal movable ones are installed as the design of the BEPCⅡ/BESⅢ. Experiments show that the movable collimators are very effective in decreasing the beam-related backgrounds, as expected. As seen clearly for both of the beams, the dark currents decrease substantially with the movable collimators from open to closed. The effectiveness of the collimator is larger for a larger single bunch current when the total beam current is the same. The collimator is also more effective in horizontal directions, whose dark currents are larger too. For a single bunch current of 6 mA, the effectiveness is as large as about 50%. During the data acquisition in the first half year of 2009, the two horizontal collimators are both set at a half aperture of 26 mm, which improves the performance of the BESⅢ when working with high luminosity under high beam currents.

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