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A Study on Beam-Beam Interactions for BTcF

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Abstract

A study on beam-beam interaction for Beijing Tau/charm Factory (BTcF) is carried out. Various parameters of the collider, such as tunes, beam-beam parameters, bunch length, beta function at the interaction points (IP), crossing angle and vertical dispersion at IP, are examined. It is concluded that with the optimized parameter set, the luminosity goal of BTcF is feasible.

1. MOTIVATION

Beam-beam interactions are one of the most important subjects for colliding machines, especially in high luminosity particle colliders. As shown in Fig. 1, BTcF is a double-ring electron-positron collider working in the τ lepton and charm meson energy region of 3-6 GeV. The target peak luminosity is $1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ at 2 GeV [1].

Fig. 1 Schematic layout of BTcF

The parameters of BTcF closely related to the beam-beam effects are listed in Table 1 together with of KEKB [2].

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Table 1 BTcF Parameters Concerning Beam-Beam Simulation

<i>Parameter</i>		<i>Unit</i>	<i>SS</i>	<i>CA</i>	<i>MC</i>	<i>KEKB LER/HER</i>
Circumference	C	m	384	384	384	3016
Beam Energy	E	GeV	2.0	2.0	1.55	3.5/8
Hori. beta function at IP	β_x^*	m	0.5	0.65	0.01	0.33
Vert. beta function at IP	β_y^*	m	0.01	0.01	0.15	0.01
Vertical dispersion at IP	D_y^*	m	0	0	± 0.35	0
Horizontal tune	ν_x		11.15	12.14	14.71	45.52/47.52
Vertical tune	ν_y		10.24	11.20	13.79	46.08/43.08
Longitudinal tune	ν_s		0.093	0.052	0.034	0.01 ~ 0.02
Horizontal emittance	ϵ_x	nm-rad	446	163	13	18
Vertical emittance	ϵ_y	nm-rad	8.9	3.3	2.6	0.36
Energy spread	σ_e	10^{-4}	5.9	5.9	8.0	7.1/6.7
Bunch length	σ_z	cm	1.0	1.0	1.0	0.4
Hori. damping ratio	τ_x/T_0		24202	24202	19518	8925/2236
Vert. damping ratio	τ_y/T_0		24202	24202	39036	8925/2236
Long. damping ratio	τ_s/T_0		12101	12101	39036	4463/2231
Vert. beam-beam param.	ξ_y		0.04	0.04	0.015	0.05
Half-crossing angle	ϕ_c	mrad	0	2.6	0	11
Bunch number	N_b		32	80	32	5000
Design luminosity	L_0	$10^{33}\text{cm}^{-2}\text{s}^{-1}$	1	1	0.2	10

It can be found from the Table 1 that the beam-beam interactions in BTcF have the following features in comparison to those in KEKB.

- With lower beam energy and larger damping ratio $\tau_{x,y,e}/T_0$, the beam-beam effects are stronger for the same ξ_y ;
- For the longer bunch ($\sigma_z/\beta_y^* \sim 1$) and larger synchrotron tune, the synchro-betatron coupling gets more important;
- The variety of collision fashions in the standard scheme (SS), the crossing angle scheme (CA) and monochromator (MC) makes the beam-beam behavior in BTcF varied and interesting.

2. ISSUES WITH BEAM-BEAM INTERACTIONS

The luminosity in a collider is expressed as

$$L_0 = \frac{k I_b^2}{4\pi e^2 f_0 \sigma_x \sigma_y} \quad (1)$$

while the bunch current I_b is limited by the beam-beam parameter

$$\xi_{x,y} = \frac{r_e \beta_{x,y}^* I_b}{2\pi \gamma f_0 e \sigma_{x,y} (\sigma_x + \sigma_y)} \quad (2)$$

where k is the number of bunches, f_0 is the revolution frequency, e and r_e are the charge and classical radius of electron, $\beta_{x,y}^*$ and $\sigma_{x,y}$ are envelope functions and beam sizes at IP respectively.

It is understood from eq.(2) that the beam-beam interaction introduces an additional kick to the partner bunch. In the linear approximation, the colliding bunches receive the equivalent quadrupole kick $\Delta k_{bb} = -4\pi\xi$. This beam-beam kick may cause a current dependence of β and beam size, called dynamic β and dynamic emittance [3], which are related to the betatron tune, shown in Fig. 2.

Fig. 2 Dynamic β and dynamic emittance

As the bunches have a finite length, the β functions at the positions where the different parts of the bunches meet are different (“hour glass” effect). Furthermore, crossing angle brings another geometrical effect to the luminosity reduction. The luminosity reduction due to the finite bunch length and crossing angle is given by [4]

$$\frac{L_g}{L_0} = \sqrt{\frac{2}{\pi}} a e^b K_0(b) \quad (3)$$

where K_0 is the modified Bessel function, a and b are defined as

$$a = \frac{\sigma_y}{\sqrt{2} \sigma'_y \sigma_z} \cos \phi_c \quad (4)$$

and

$$b = a^2 \left[1 + \left(\frac{\sigma_z}{\sigma_x} \tan \phi_c \right)^2 \right] \quad (5)$$

The horizontal flat beam ($\sigma_y \ll \sigma_x$) is assumed in eq.(4). In the case of the vertical flat beam ($\sigma_x \ll \sigma_y$, happens in the monochromator scheme) the subscript “y” in eq.(4) should be replaced with “x”. On the other hand, the eq.(5) is applied to the horizontal crossing scheme, while in the case of vertical crossing, the subscript “x” should be replaced with “y”. The geometric luminosity as a function of β'/σ_z and b defined in eq.(5) is exhibited in Fig. 3. It

can be found in the figure that luminosity reduces with the decreasing of β^*/σ_z and increasing of ϕ_c . The luminosity drops steeply with the decreasing of β^* to σ_z ratio in the region β^*/σ_z less than 1, while the variation of the luminosity with crossing angle is rather smooth.

Fig. 3 Geometric luminosity reduction

Above discussion on the beam-beam issues is based on the simplified models and linear approximation. In reality, the beam-beam effects are much more complicated. The interactions may bring two beams onto linear and nonlinear resonance, the beam size will blow-up, the tail may grow and beam distribution will no longer be Gaussian. Therefore, the computer simulation is necessary in order to study the complexity of the nature for beam-beam interaction.

3. SIMULATION ALGORITHM

The simulation is performed by taking advantage of the computer code BBC (Beam-Beam interaction with a Crossing angle) developed by K.Hirata [4]. The algorithm applied in the code is illustrated in the following chart:

$$x(0) \xrightarrow{\mathcal{L}} x^*(0^*) \xrightarrow{SBM} x^*(0^*) \xrightarrow{\mathcal{L}^{-1}} x(0) \xrightarrow{Ring} x(0) \xrightarrow{\mathcal{L}} \dots$$

Two bunches colliding at a crossing angle are first Lorentz-transformed into a frame where their momentum vectors appear parallel, shown in Fig. 4.

Fig. 4 Lorentz transformation from the laboratory frame to the “head on frame”

In this head-on frame, the beam-beam forces and their effects on the opposite bunches are computed using a symplectic Synchro-Beam Mapping (SBM) [5]. When the SBM is carried out, the two bunches are inversely Lorentz-transformed back to the laboratory frame and the beam tracking code takes over the rest of the simulation. In principle, this idea could be applied to a general strong-strong case at the interaction points and real lattice. However, our present study is based on the strong-weak case and linear lattice. A simplified radiation damping and fluctuation effects are added in the linear transformation in the arcs [3]. In the transverse case, the $(u, u')^t$ changed to

$$\lambda \begin{pmatrix} \cos \mu & \beta_0 \sin \mu \\ -\frac{\sin \mu}{\beta_0} & \cos \mu \end{pmatrix} \begin{pmatrix} u \\ u' \end{pmatrix} + \sqrt{1 - \lambda^2} \begin{pmatrix} r_1 \\ r_2 \end{pmatrix} \quad (6)$$

where u denotes x or y , $\mu = 2\pi\nu$, $\lambda = \exp(-\tau/T_0)$, r_1 and r_2 are Gaussian random numbers with unit r.m.s. value. The formula in the longitudinal case is similar.

The strong bunch is longitudinally divided into 5 slices and the weak one is represented by 50 super-particles whose initial coordinates in 6-dimensional phase space are randomly generated. The beam-beam collision and the circulation around the ring are simulated for more than 10 radiation times. The simulation takes the machine parameters listed in the Table 1 except those specified as variables in the input data files for mapping study. In our weak-strong simulation, the distribution of weak beam changes due to the beam-beam interaction, while the strong beam remains Gaussian. The distribution of the weak beam is obtained by simulation as the sum of delta-functions, which represent the ensemble of particles. The simulated luminosity L is computed as a convolution of the distribution function of both weak and strong beams. The geometric luminosity reduction is calculated in a post-processing Mathematica program using eq. (3)-(5). Furthermore, two additional definitions of luminosity are introduced. First one (L_1) is defined as in such a way that

$$\sigma_u = \sigma_{u,w} = \sigma_{u,s} \quad (7)$$

is applied to eq.(1) and eq.(3). Where subscript “ u ” denotes “ x ” or “ y ”, and $\sigma_{u,w}$ is the size of the weak beam obtained from the simulation, while $\sigma_{u,s}$ is the strong beam size. The second one L_2 is defined in a same way of L_1 but

$$\sigma_u = \frac{1}{\sqrt{2}} (\sigma_{u,0}^2 + \sigma_{u,w}^2)^{1/2} \quad (8)$$

It is easy to be realized that the beam-beam blow-up is overestimated with eq.(7) so that L_1 is somewhat pessimistic value of the luminosity. On the other hand, the eq.(8) might be a compensation for the overestimated effect.

4. BEAM-BEAM SIMULATION FOR STANDARD SCHEME

4.1 Beam-Beam Tune Scan

The purpose of beam-beam tune scan is to examine the design luminosity and to optimize the tunes. Figure 5 gives the simulated luminosity scanned on the fractional tune plane $\delta\nu_x \in (0,1)$, $\delta\nu_y \in (0,1)$ (for simplicity, the adjective “fractional” will be omitted, and ν instead of $\delta\nu$ will be used in the following text) for the standard scheme. The mesh size is 0.025, which is smaller than the synchrotron tune $\nu_s = 0.093$. In the figure, the magnitude of

luminosity is presented with the degree of gray scale, the darker the gray the higher the luminosity. The contour spacing is $5 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$.

Fig. 5 Luminosity scan on v_x - v_y plane for the standard scheme

Fig. 6 Vertical beam-size scan on v_x - v_y plane for standard scheme

It can be seen from Fig. 5 that the luminosity in the four quadrants divided by the lines of $\nu_x = 0.5$ and $\nu_y = 0.5$ are about identical. The luminosity reduction due to the beam-beam force driven resonance of $\nu_y \pm \nu_s = k$, $2\nu_y \pm \nu_s = k$, $\nu_x \pm \nu_s = k$, $2\nu_x \pm \nu_y = k$ and $\nu_x \pm 2\nu_y = k$ is clearly seen, where k is integer. The major reason of the luminosity reduction can be found in the Fig. 6 as the vertical beam size blow-up, in which the darker (larger beam size) place just fits the lighter (lower luminosity) one in Fig. 5.

Figure 7 gives a 3-dimensional display of luminosity on the tune plane, which shows that the luminosity strongly depends on the working points and the goal of $1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ could be realized with the optimized tunes.

Fig. 7 A 3D-display of luminosity scan on ν_x - ν_y plane for standard scheme

As shown in Fig. 5 and Fig. 7, the maximum luminosity appears right above the half integer resonance. A slice from luminosity contour diagram for $\nu_y = 0.10$, $\nu_x \in (0,1)$ is plotted in Fig. 8.

Fig. 8 Luminosity as a function of ν_x with $\nu_y = 0.10$ for standard scheme

Again, the figure shows a significant tune dependence of the luminosity. The curves of simulated luminosity L/L_0 as well as L_1/L_0 , L_2/L_0 defined with eq.(7) and eq.(8) have a similar structure and $L > L_2 > L_1$, which can be explained as the overestimate of beam size for L_1 (see eq.(7)) and the tail growing. Instead of simply taking the r.m.s. beam sizes for σ_x and σ_y in eq.(1) to calculate luminosity, the simulation provides the more reliable luminosity value, which will be regarded as “luminosity” in this paper.

The simulation shows that higher luminosity is expected at the working points around $v_x=0.07$ and $v_y=0.10$. These optimized tune values are taken for the beam-beam parameterization described in the rest parts of this section.

4.2 Is it Possible to Get β_y^* Smaller?

In order to enhance luminosity, the β function in IP should be as small as possible. On the other hand, the smaller the β^*/σ_z value, the larger the geometric luminosity reduction. The luminosity reduction due to the “hour glass” effect for $\phi_c=0$ is plotted in Fig. 9. For the design bunch length of 1 cm, the curve gives $L_g/L_0=0.86$.

Fig. 9 Geometric Luminosity reduction due to the “hour glass” effect

Figure 10 displays the luminosity scanned on the $\beta^* - \sigma_z$ plane with the contour spacing of $5 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$. The simulation agrees with the analytic curve shown in Fig. 9 that significant luminosity reveals above the diagonal line of Fig. 10 ($\sigma_z > \beta^*$). In Fig. 11, the simulated luminosity L/L_0 is plotted together with geometric luminosity L_g/L_0 and vertical beam size in the case of $\sigma_z = 1 \text{ cm}$. As shown in the figure, L/L_0 closes to L_g/L_0 when $\beta^* > 0.75\sigma_z$, while below that value, L/L_0 curve drops steeper than L_g/L_0 . The reason, also shown in Fig. 11, is the significant vertical beam size blow-up caused by synchro-betatron coupling.

Fig. 10 Luminosity L/L_0 scanned on β_y^* - σ_z plane for the standard scheme

Fig. 11 Luminosity and vertical beam size vs. β^* for $\sigma_z=1$ cm

It is then concluded from above discussion that the $\beta_y^*/\sigma_z < 1$ is not wise choice, in other words, β_y^* might be reduced from the design value of 1 cm only if σ_z could be made smaller than 1 cm.

3.3 Is it Possible to Get ξ_y Larger?

It can be found from eq. (1) and eq. (2) that the larger the beam-beam parameter ξ (especially ξ_y) reaches, the higher the luminosity can be obtained. However, the maximum value of ξ_y is limited by the beam-beam interaction. The luminosity as a function of ξ_y is plotted in Fig. 12.

Fig. 12 Luminosity and vertical beam size vs. ξ_y

As shown in the figure, the vertical beam size blow-up takes place for non-zero ξ_y . However, the blow-up does not behavior monotonously. This is understood as the dynamic emittance and β effects. The design value of $\xi_y=0.04$ sites near the bottom of y_{rms}/σ_y and peak of L/L_0 curves. The relative luminosity keeps around or above the analytic values of the luminosity for $\xi_y \in (0,0.05)$ at the optimized tunes of $\nu_x=0.07$ and $\nu_y=0.10$. The simulation confirms the design value of $\xi_y=0.04$ is reasonable with certain safety margin.

5. CROSSING ANGLE SCHEME

Crossing angle collision was pioneered in DORIS with $\phi_c=12$ mrad vertically, where the synchro-betatron coupling oscillation was observed [6]. In CESR, a horizontal crossing angle of 2×2.5 mrad is applied with success [7]. In the recent design of KEKB, a crossing angle scheme is adopted with a intensive study [8]. By taking advantage of crossing with angles in colliders, the separation of the electron and positron beams gets easier and the number of bunches to be brought onto collision can be increased so that the luminosity could be enhanced. However, the side effects are the geometric luminosity reduction and the synchro-betatron resonance due to the beam-beam interaction need to be studied with care.

Figure 13 exhibits the geometric luminosity reduction for different schemes of BTcF at the design value of $\beta^*/\sigma_z=1$. It can be seen from the figure that the geometric luminosity reduction due to the crossing angle is negligible in the region of interest for standard and crossing angle schemes if horizontal crossing is applied, while it is significant in the case of vertical crossing.

Fig. 13 Geometric luminosity reduction vs. crossing angle for $\beta^*/\sigma_z=1$

5.1 Tune Scan for Crossing Angle Scheme

Figure 14 shows the luminosity diagram on the v_x - v_y plane for a crossing angle of 2×2.6 mrad. The contour spacing is $5 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$. The luminosity as a function of v_x with $v_y=0.10$ is plotted in Fig. 15.

Fig. 14 Luminosity scan on v_x - v_y plane for crossing angle scheme ($\phi_c=2.6$ mrad)

Fig. 15 Luminosity as a function of v_x with $v_y = 0.10$ for crossing angle scheme

Again, exhibited in Fig. 14 and Fig. 15, higher luminosity appears right above the half integer tunes and Fig. 15 is similar to those in Fig. 8. As shown in the Table 1, the luminosity goal of $1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ can be reached with a smaller beam emittance in the crossing angle scheme and then lower current per bunch but more bunches in the ring, so that the restriction to the single bunch effects, especially the bunch lengthening, could be released. The question remains how large the crossing angle is acceptable?

5.2 How Large the Crossing Angle is Acceptable?

The luminosity reduction due to the crossing angle has been discussed in the section 2. As shown in the Fig. 13, the reduction is rather small in the crossing angle scheme of $\phi_c = 2.6$ mrad. On the other hand, beam-beam interaction might become more serious when the crossing angle increases. Figure 16 exhibits the simulation results by showing the luminosity and vertical beam size vs. crossing angle.

Fig. 16 Luminosity L/L_0 and vertical beam size vs. crossing angle

The simulation results plotted in Fig. 16 show that in the range of interest of $\phi_c < 10$ mrad, the vertical beam size keeps about constant and luminosity is in good agreement with the analytic curve for $\xi_y=0.04$ and chosen tunes of $v_x=0.08$, $v_y=0.10$. The simulation suggests that it is possible to increase the crossing angle to around 10 mrad if it would help to increase the bunch number and then enhance the luminosity and other design aspects.

6. BEAM-BEAM INTERACTION IN THE MONOCHROMATOR

The monochromator scheme provides a narrow center-of-mass energy spread in the collider. This is achieved by means of opposite orbit dispersions of electron and positron beams. The vertical dispersion functions at IP is chosen as ± 0.35 m (see Table 1) for BTcF monochromator. The large dispersion function makes the vertical beam size dominated by the orbit dispersion ($\sigma_y/\sigma_{y\beta} \sim 14$) and vertical flat beam ($\sigma_y/\sigma_x \sim 24$) in the monochromator. A particle with the momentum error of δ receives a kicker from the opposite beam:

$$\Delta k_{B-B} = -4\pi \beta_y^* (y + D_y^*) \xi_y \delta \quad (9)$$

This momentum dependent beam-beam kick may drive synchro-betatron resonance. The monochromator scheme has nowhere been tested and the beam-beam interaction needs to be studied carefully.

6.1 Tune Scan in Monochromator

The tune scan is done based on the parameters listed in Table 1. The mesh size of 0.02 is a little smaller than $v_s = 0.034$, the vertical beam-beam parameter is chosen as 0.015. Figure 17 pictures a 3-dimensional vertical betatron beam size on the v_x - v_y plane. The resonance lines of $v_y \pm v_s = k$, $2v_y \pm v_s = k$, $3v_y \pm v_s = k$, $4v_y \pm v_s = k$ are clearly seen in the figure. A linear theory is being worked out to explain the beam-beam effects in monochromator [9].

Fig. 17 Vertical beam size scan on v_x - v_y plane for monochromator

Figure 18 shows a luminosity contour on the v_x - v_y plane. The spacing of the contour lines is $1 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$. Some of resonance lines of $nv_y \pm v_s = k$, n being integer, are shown in the figure, their influence on the luminosity is not significant. This can be understood as the vertical beam size is dominated by orbit dispersion in the monochromator case. However, the blow-up of the vertical betatron beam size will degrade the monochromatization and should be avoided.

Fig. 18 Luminosity scan on v_x - v_y plane for monochromator

The beam size blow-up can be reduced by a careful choose of the tunes. Fig. 19 plots the luminosity curve as function of v_y with $v_x=0.58$.

Fig. 19 Luminosity vs. v_y with $v_x=0.58$ for monochromator

As the design tunes are in the region of (0.5,1.0), we choose $\nu_x=0.58$ and $\nu_y=0.72$ for the further study. The simulation suggests to take the vertical tune around 0.2 with $\nu_x=0.58$ or 0.08 where the luminosity curve are flat and above the analytic value.

6.2 Beam-Beam Parametarization in Monochromator

Two parameters are taken into account in our survey, i.e. beam-beam parameter ξ_y and vertical dispersion D_y^* . Fig. 20 displays the luminosity contour diagram on the ξ_y - D_y^* plane with the spacing of contour lines of $1 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$.

Fig. 20 luminosity L/L_0 contour diagram on ξ_y - D_y^* plane for monochromator

Shown in Fig. 20, the luminosity L/L_0 reduces with the increasing of D_y^* for the same ξ_y . In other words, the maximum achievable ξ_y depends on D_y^* . Fig. 21 exhibits the slice of the Fig. 20 at $D_y^*=0.35 \text{ m}$.

It is seen in Fig. 21 that the luminosity reduced steeply with the increase of ξ_y when it is larger than 0.02. At the ξ_y value of 0.04 taken for the standard and crossing angle schemes, the vertical and horizontal beam blow-up factors are about 19 and 3 respectively while L/L_0 drops to about 0.28. The design beam-beam parameters $\xi_y=0.015$ and $\xi_x=0.028$ sit at a quite comfort region where no significant blow-up takes place and luminosity closes to the analytic value.

Fig. 21 Luminosity and beam size vs. ξ_y with $D_y^*=0.35$ m for monochromator

Luminosity and beam size as functions of vertical dispersion is shown in Fig. 22. The vertical beam size increases significantly with the increase of the vertical dispersion, while the horizontal size and luminosity change smoothly. The beam size blow-up and luminosity drop become unacceptably large when $D_y^*>0.7$ m. Our design value of $D_y^*=0.35$ m seems a good choice with some safety margin.

Fig. 22 Luminosity and beam size as functions of vertical dispersion at IP

7. SUMMARY

The beam-beam simulation is carried out to examine the beam-beam effects and the feasibility of the luminosity goal of BTcF.

1. The present strong-weak simulation indicates that the BTcF's luminosity goals of $1 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ for the standard and crossing angle schemes and $2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ for monochromator are feasible.
2. The maximum beam-beam parameter for BTcF is simulated as around 0.05 and 0.02 for the standard scheme and monochromator respectively. Present design values of 0.04 and 0.015 are with some margins.
3. The simulation has shown good hopes of the crossing angle scheme in BTcF. With the design value of BTcF, the geometrical luminosity loss is small and the beam-beam stability can be well kept. It is recommended to increase the bunch numbers by taking advantage of this scheme in order to enhance the luminosity.
4. The beam-beam tune scan shows a significant tune dependence of luminosity and beam size. The dynamic β and dynamic emittance effect is verified by the simulation. Higher luminosity could be obtained for the tunes just above a half integer. It is suggested that the lattice design of BTcF should be capable to provide the flexibility for tune adjustment and its stability.
5. The vertical dispersion in the monochromator may cause the synchro-betatron resonance. The simulation shows the significant beam size blow-up and luminosity reduction when ξ_y is above than 0.02 ($D_y^* \approx 0.35 \text{ m}$) or D_y^* larger than 0.7 m ($\xi_y = 0.015$). By carefully choosing tunes, the beam size blow-up can be avoided for the present design of $\xi_y = 0.015$ and $D_y^* = 0.35 \text{ m}$.
6. The simulation verifies the geometric luminosity reduction due to "hourglass effect" and crossing angle. It is suggested to reduce the ratio of β^*/σ_z (to, say 0.75) in order to reduce the 14 % luminosity loss due to this effect in the present design of $\beta^*/\sigma_z = 1$. The simulation also indicates the luminosity drop in the range of $\sigma_z \geq 1.25\beta_y^*$. The bunch length and its lengthening are one of the central concerns in our beam-beam study for BTcF.
7. The simulation indicates that the beam-beam interaction will cause the vertical beam blow-up especially the non-Gaussian tail growing with the increasing of beam-beam parameter ξ_y , crossing angle ϕ_c and bunch length σ_z . The tail may cause extra background to the detector due to synchrotron radiation and particle loss. The tail problem needs to be studied carefully and a sophisticated mask system is necessary for the high luminosity data collection.
8. Present beam-beam study is based on the strong-weak interaction and linear lattice. In the further study, the strong-strong model and non-linear lattice will be taken into account.

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