Beam loss background and collimator design in CEPC double ring scheme

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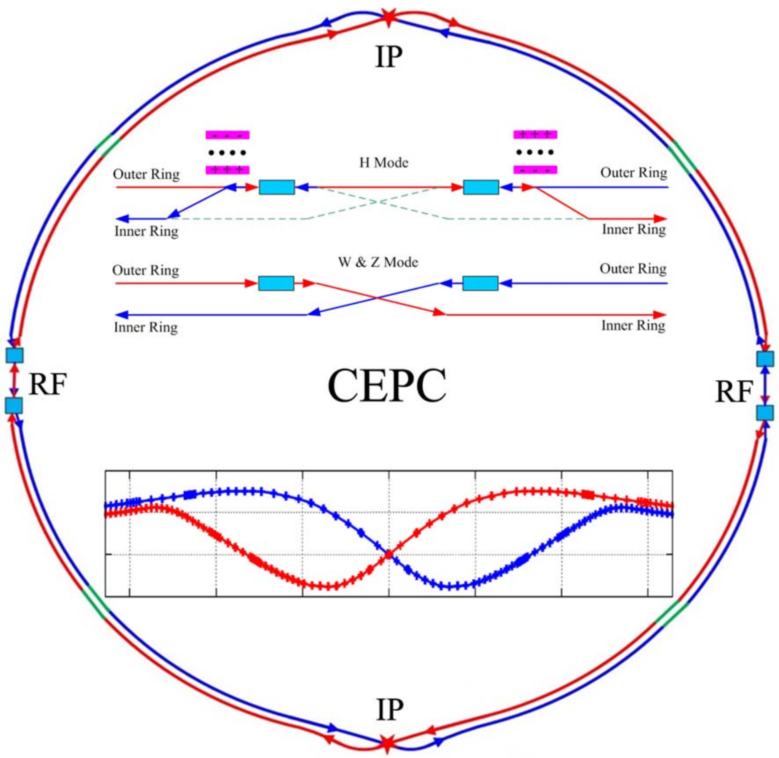
Outline

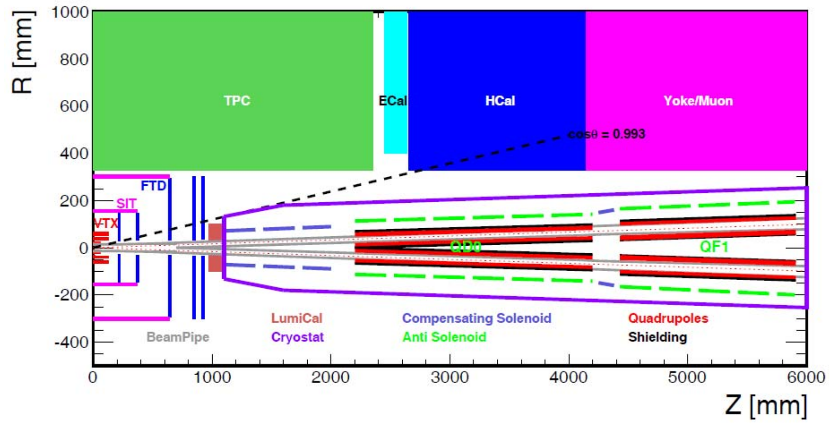
- Introduction to CEPC double ring scheme and beam loss background
- CEPC beam lifetime
- Beam loss backgrounds
- Collimator design
- Summary

IPAC18

Introduction



- **3 energy modes:**
  Higgs, W, Z
  (120GeV, 80GeV, 45.5GeV)
- Circumference C_0 **=100km**
- N_{IP} **=2**
- Beam power P_0 **≤30MW**
- β_y^* **=1.5mm**
- Crossing angle θ **=33mrad**
- Shared RF @ H
- Independent RF @ W & Z



- The Machine Detector Interface (MDI) of CEPC double ring scheme is about ±7m long from the IP
- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993.

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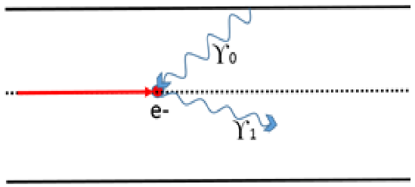
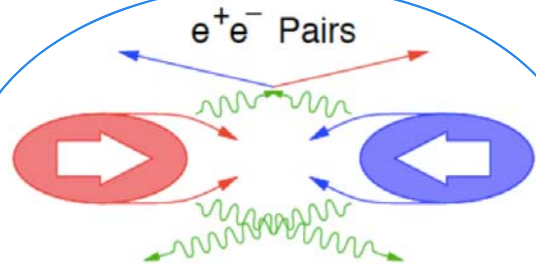
Beam loss Backgrounds at CEPC



Beam-Thermal photon scattering



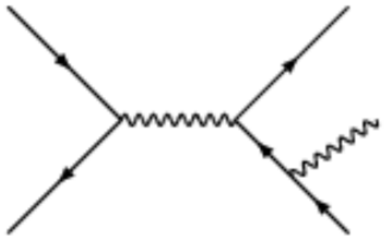
Beamstrahlung

IP1

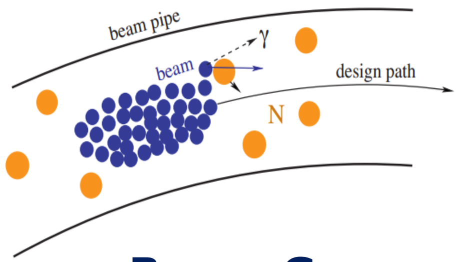
242 bunches
Revolution frequency: **2997**Hz
1.5×10^{11} particles/Bunch
L: $3 \times 10^{34} cm^{-2} s^{-1}$

IP3

Beam Lost Particles
Energy Loss > 1.5%
(energy acceptance)



Radiative Bhabha scattering

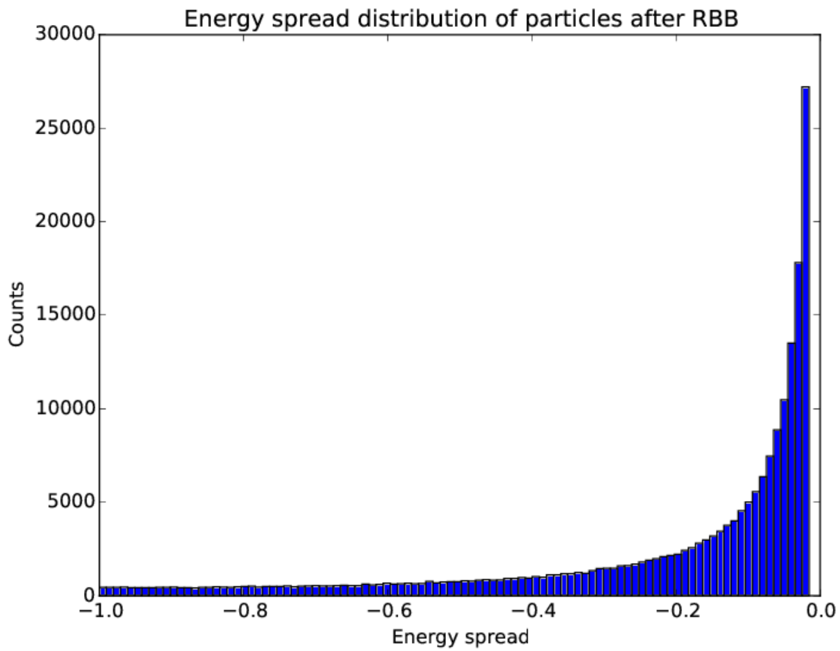


Beam-Gas Scattering

CEPC beam lifetime

	Beam lifetime	others
Quantum effect	>1000 h	
Touscheck effect	>1000 h	
Beam-Gas (Coulomb scattering)	>400 h	Residual gas CO， 10^{-7}Pa
Beam-Gas (bremsstralung)	63.8 h	
Beam-Thermal photon scattering	50.7 h	
Radiative Bhabha scattering	100 min	
Beamstrahlung	60 min	

Radiative Bhabha scattering events

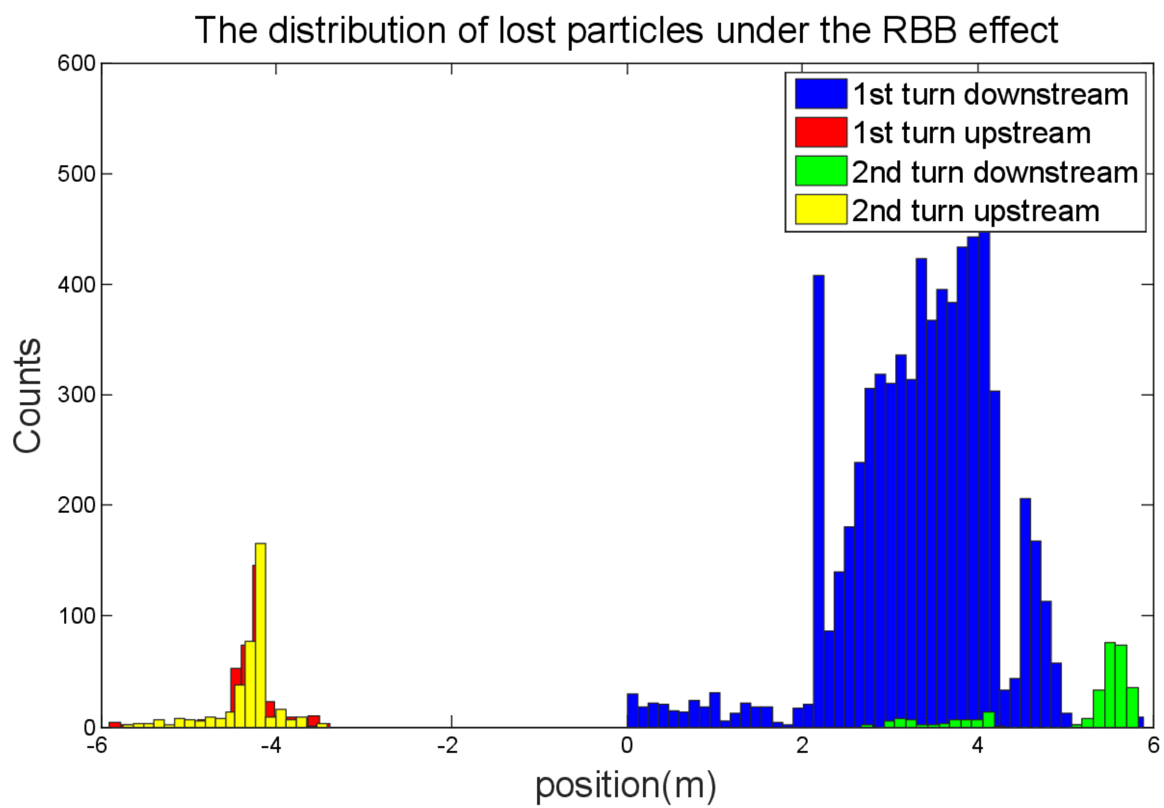


- According to the off-momentum dynamic aperture after optimizing the CEPC lattice, and considering the beam-beam effect and errors, the energy acceptance of CEPC is about 1.5%.
- Radiative Bhabha scattering is simulated by BBBrem or Py_RBB.
- Generate 2e+5 particles.

RBB lost particles statistic

~first two turns

- Set aperture according to beam pipe
- RBB generated at IP1, tracking in SAD
- The position and coordinate in phase space of lost particles near the IP are recorded.
- Most the events lost in the detector immediately. A few particles with high energy will lost near the IP after one revolution for a small energy loss.
- Although pretty large fraction of events lost in the downstream region, the radiation damage for detector component is tolerable.



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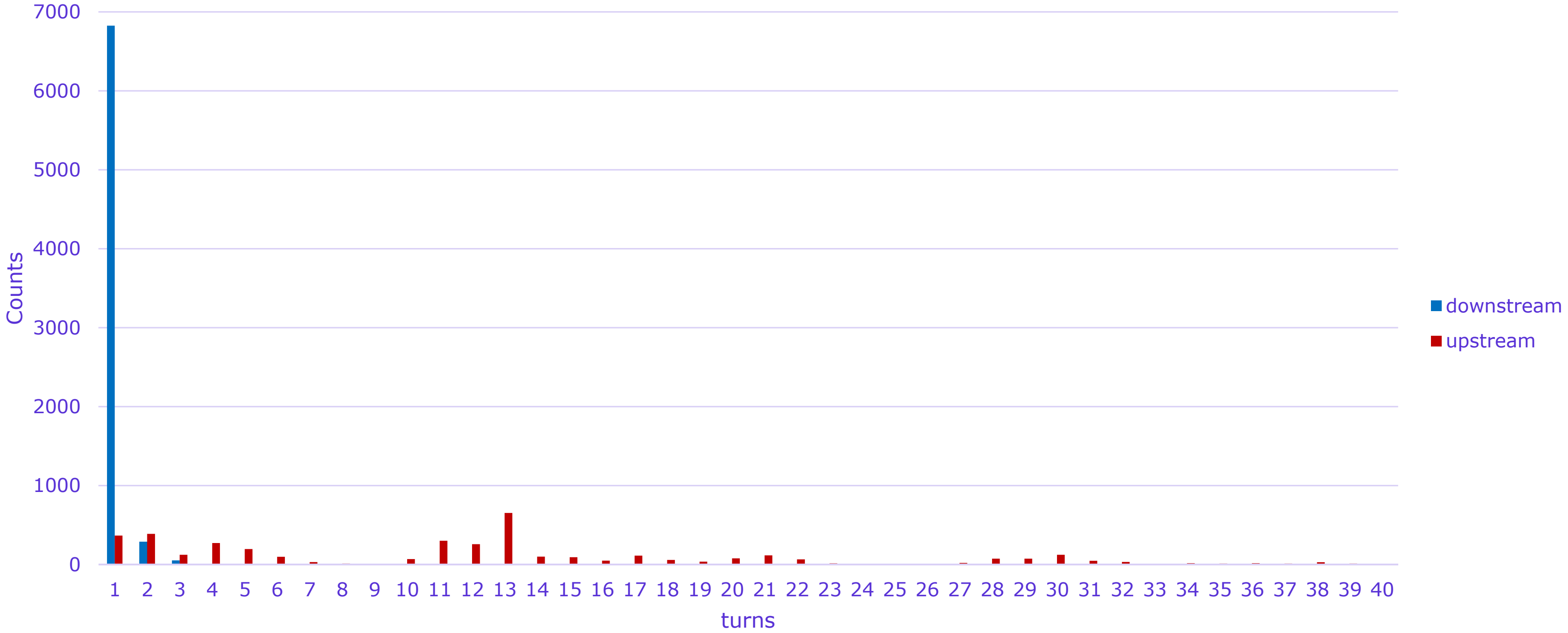
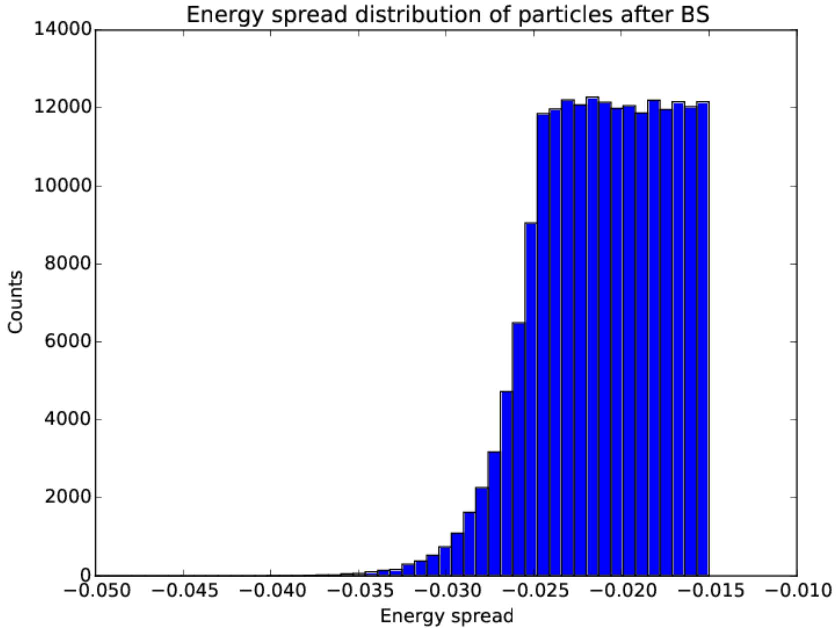
Loss particles due to RBB in multi-turn



- Compared to the one turn's tracking, more particles get lost in the upstream region of the IR.
- The events lost in the upstream region are more dangerous for they are likely permeate into the detector components, even with the small flying angle respect to the longitudinal direction considered.
- Collimators are needed.

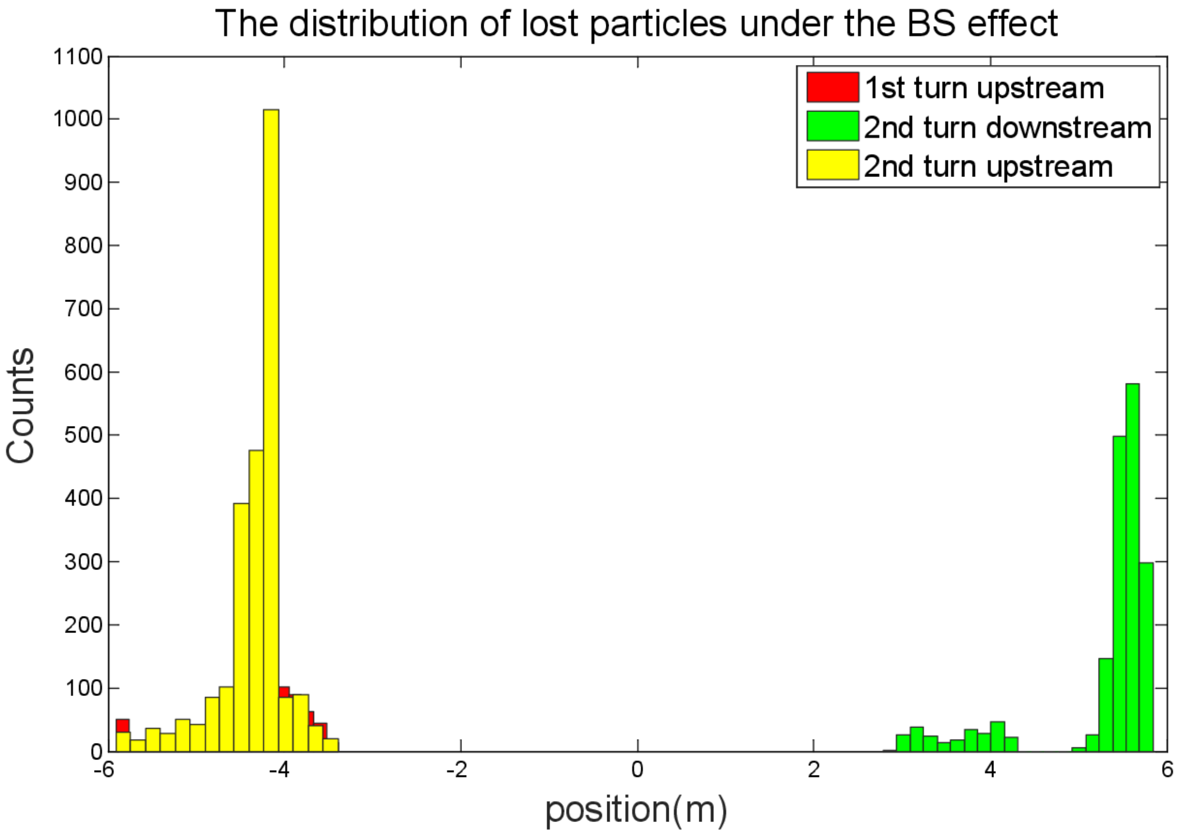
Beamstrahlung events



- High energy photons from beamstrahlung can interact with each other and induce electron-positron pair production or hadronic background. Also, if the energy spread is larger than the energy acceptance, particles might be lost.
- Beamstrahlung events have been generated with Guinea-Pig++ or Py_BS.
- Generate 200000 particles.

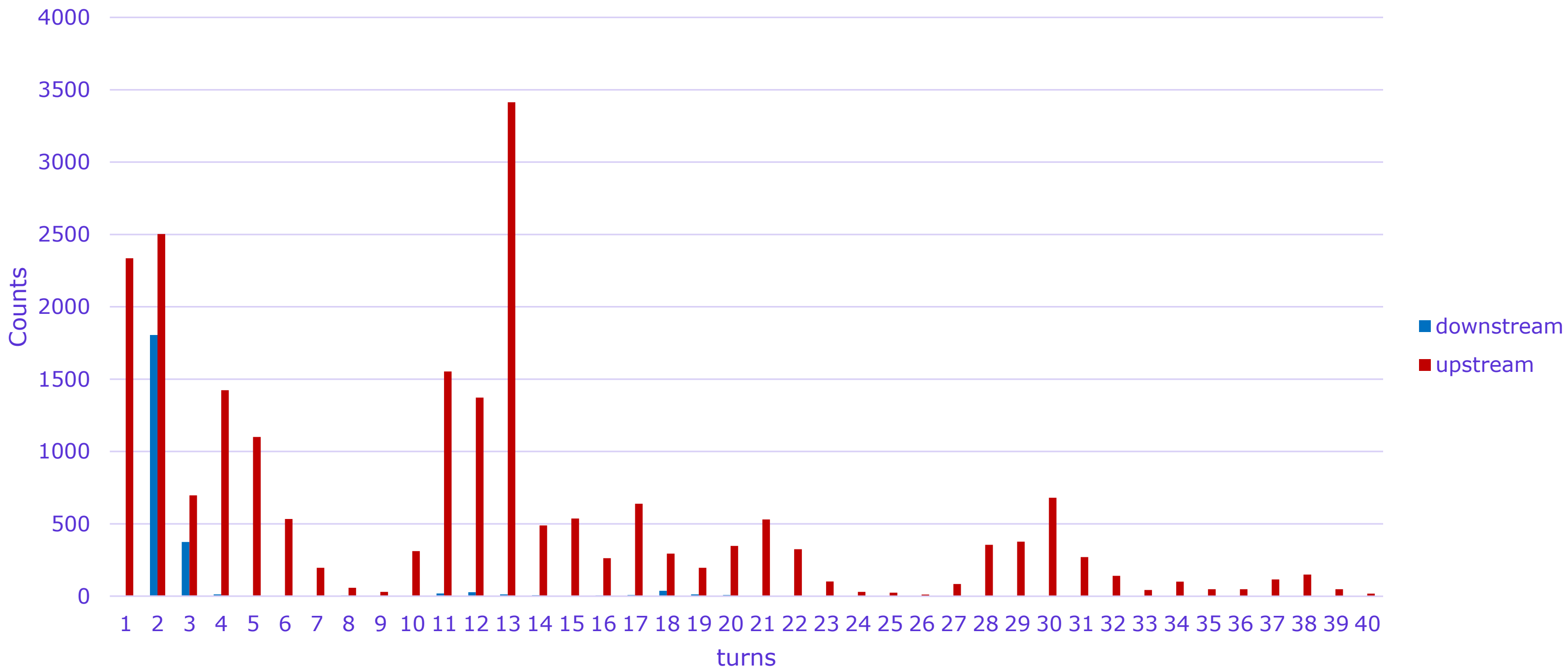
BS lost particles statistic

~first two turns tracking



- Set aperture according to beampipe
- BS generated at IP1, tracking in SAD
- The position and coordinate in phase space of lost particles near the IP are recorded.
- Energy spread distribution close to the energy acceptance, the beam loss particles not appeared in the downstream of first turn.

Loss particles due to BS in multi-turn tracking



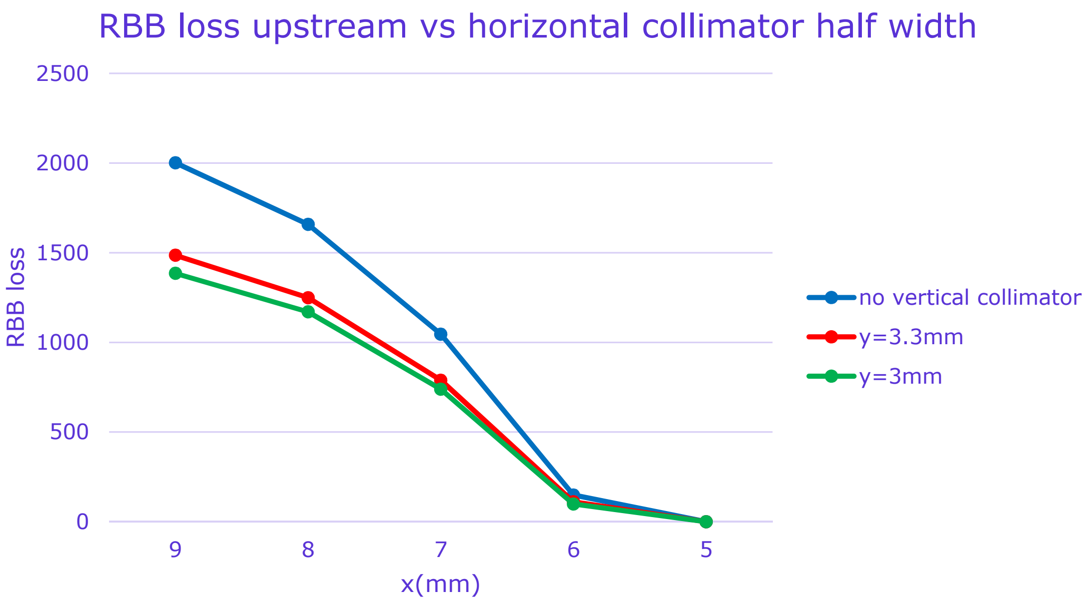
- Compared to the one turn's tracking, more particles get lost in the upstream region of the IR.
- The events lost in the upstream region are more dangerous for they are likely permeate into the detector components, even with the small flying angle respect to the longitudinal direction considered.
- Collimators are needed.

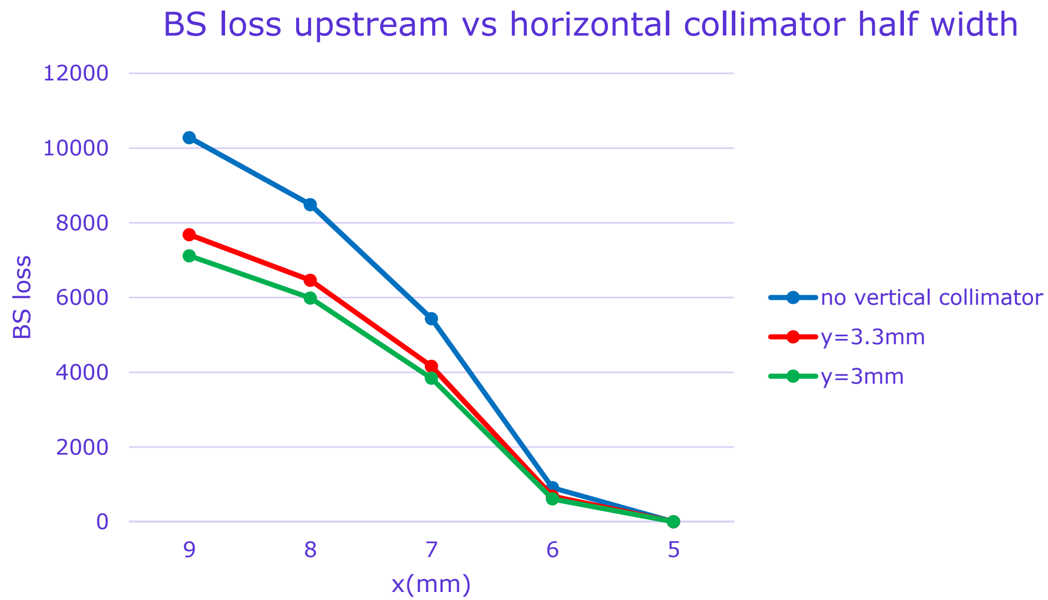
Collimator design in ARC for Higgs

- Beam stay clear region: 18 σ_x+3mm, 22 σ_y+3mm
- Impedance requirement: slope angle of collimator < 0.1
- To shield big energy spread particles, phase between pair collimators: $\pi/2+n*\pi$
- Collimator design in large dispersion region: $\sigma=\sqrt{\varepsilon\beta+(D_x\sigma_e)^2}$

name	Position	Distance to IP/m	Beta function/m	Horizontal Dispersion/m	Phase	BSC/2/m	Range of half width allowed/mm
APTX1	D1I.1897	2139.06	113.83	0.24	356.87	0.00968	2.2~9.68
APTX2	D1I.1894	2207.63	113.83	0.24	356.62	0.00968	2.2~9.68
APTX3	D1O.10	1832.52	113.83	0.24	6.65	0.00968	2.2~9.68
APTX4	D1O.14	1901.09	113.83	0.24	6.90	0.00968	2.2~9.68

RBB loss with horizontal collimator half width





- Only horizontal collimator are selected, vertical collimators are not needed.
- Vertical collimators are usually placed very close to the beam, no vertical collimators to avoid transverse mode coupling instability.

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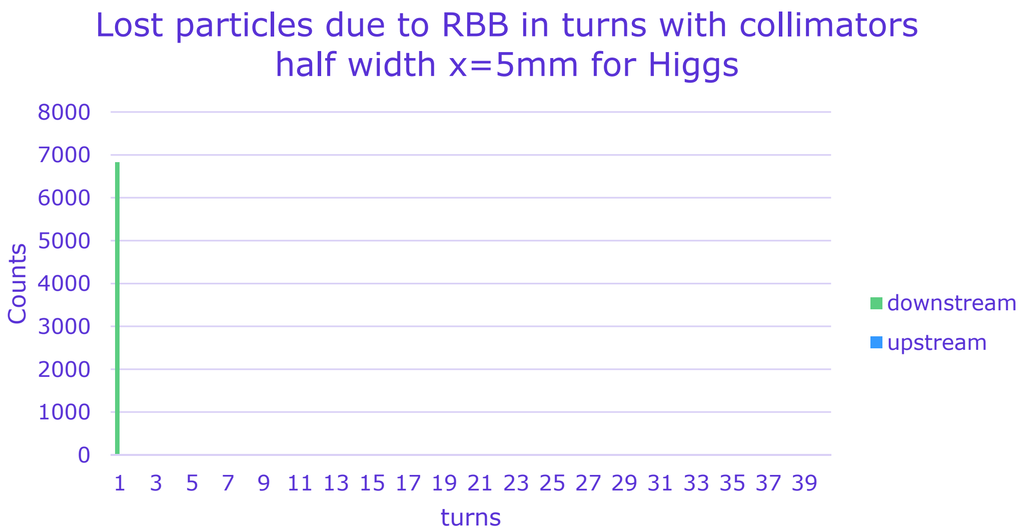
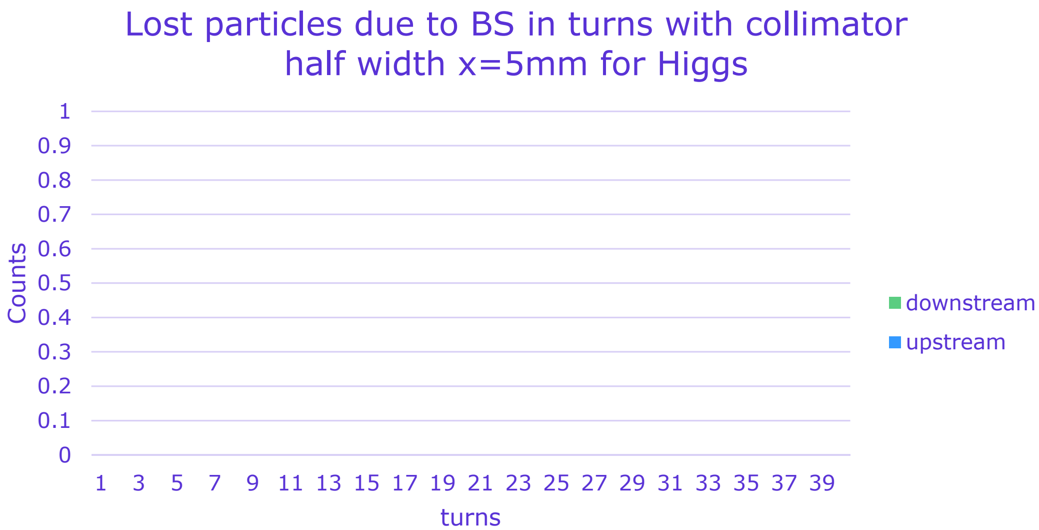
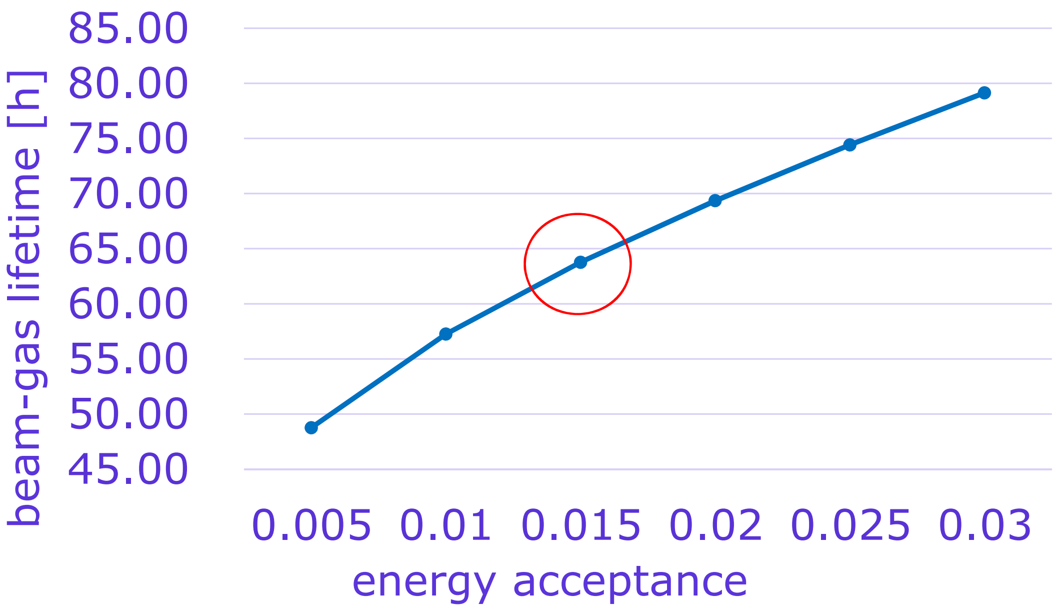
RBB and BS loss with collimators for Higgs

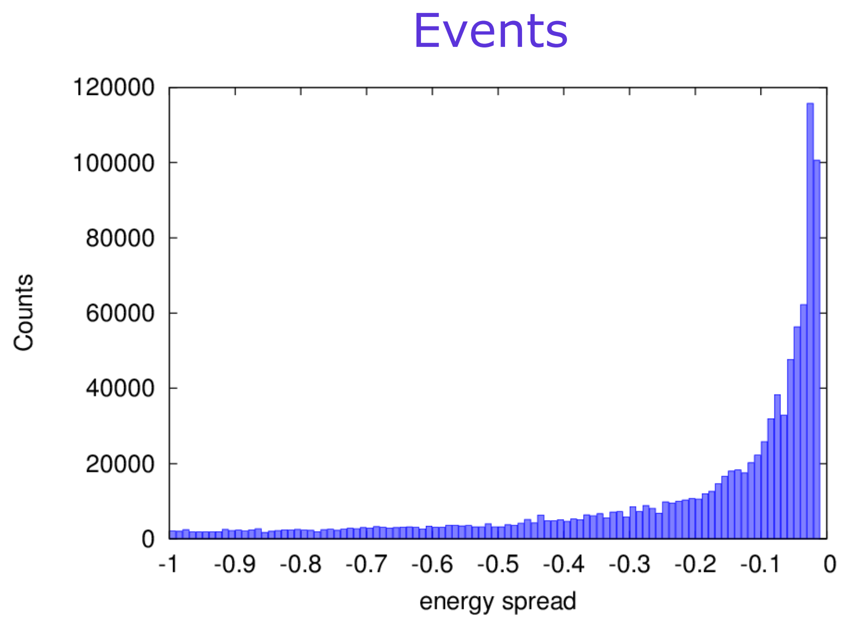




- horizontal collimator half width 5mm(13σ_x)
- The collimators will not have effect on the beam quantum lifetime.
- The lost particles has been reduced to a very low level with the system of collimators, especially in the upstream of the IP.
- Although the beam loss in the downstream of the IP is still pretty large in the first turn tracking, the radiation damage and the detector background are not as serious as the loss rate for the relative small flying angle to the ideal orbit.

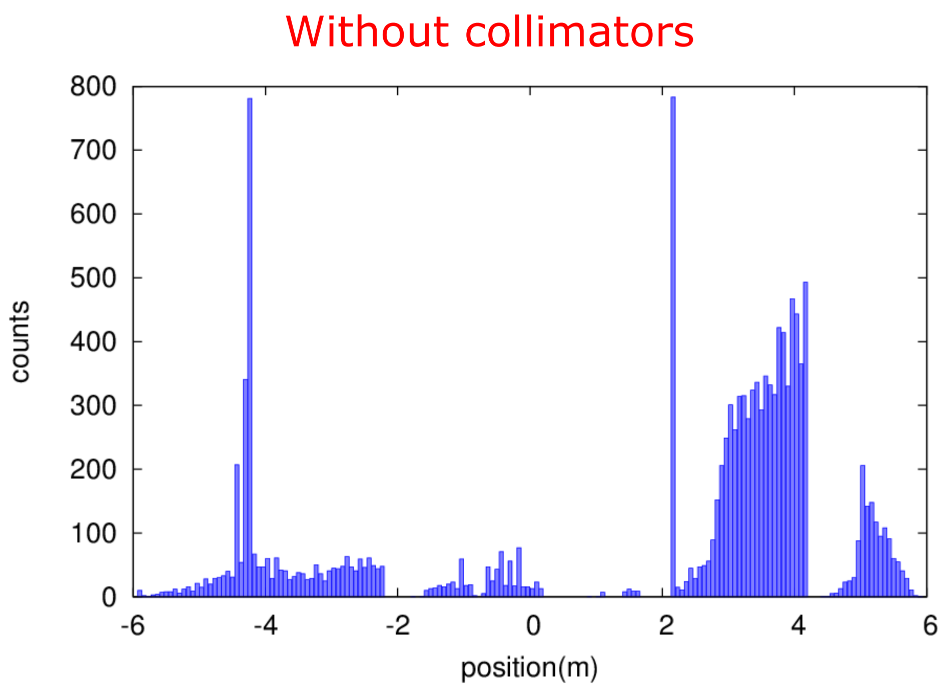
Beam-Gas bremsstrahlung in Higgs

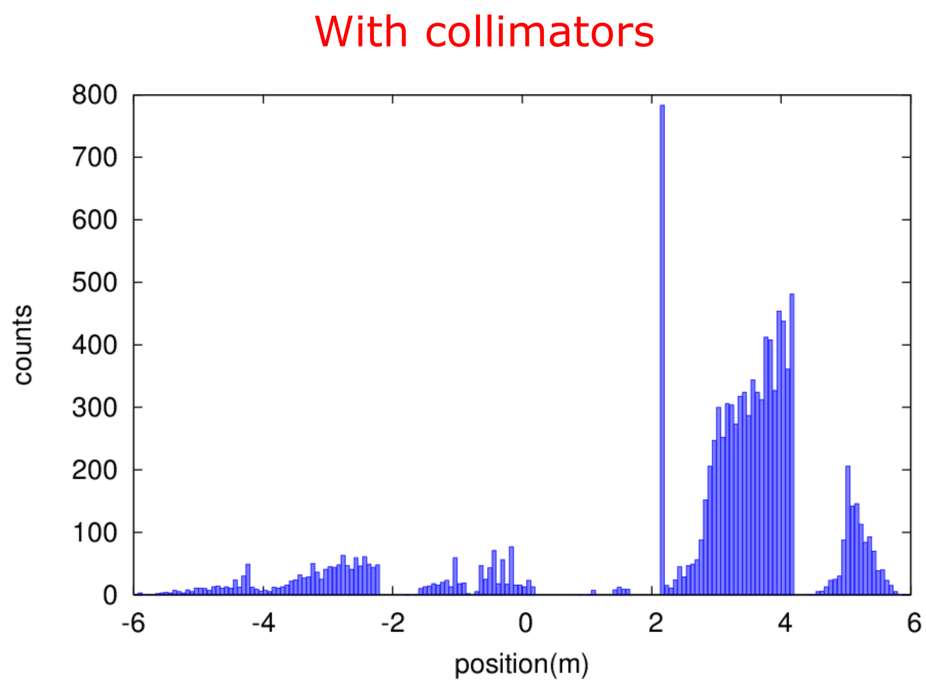




- According to the off-momentum dynamic aperture after optimizing the CEPC lattice, and considering the beam-beam effect and errors, the energy acceptance of CEPC is about 1.5%.
- When the energy acceptance is 1.5%, the beam-gas bremsstrahlung lifetime is about 63.8 hours.
- Generate ~ 100000 particles.

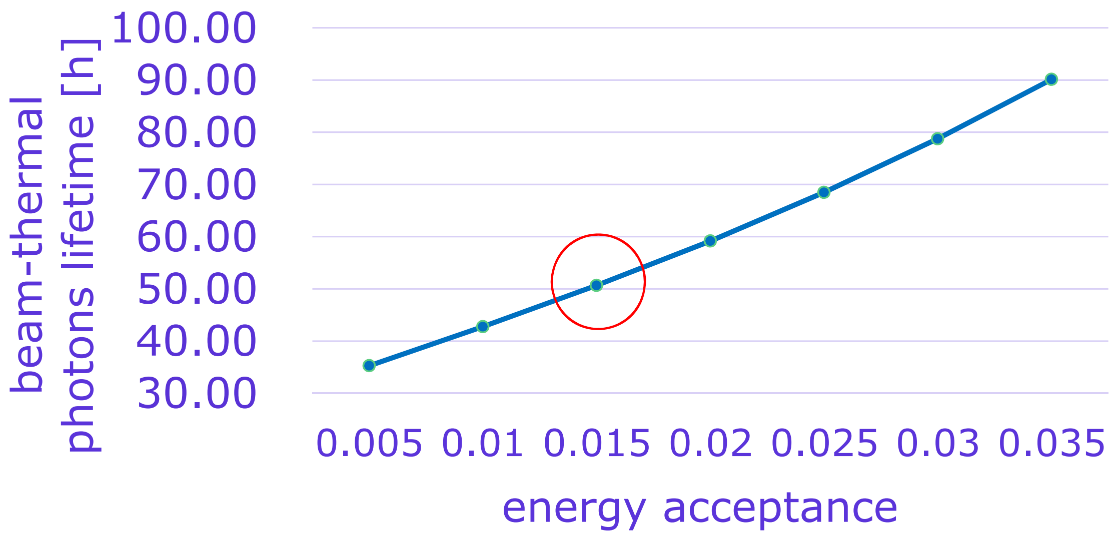
Beam-Gas bremsstrahlung loss particles

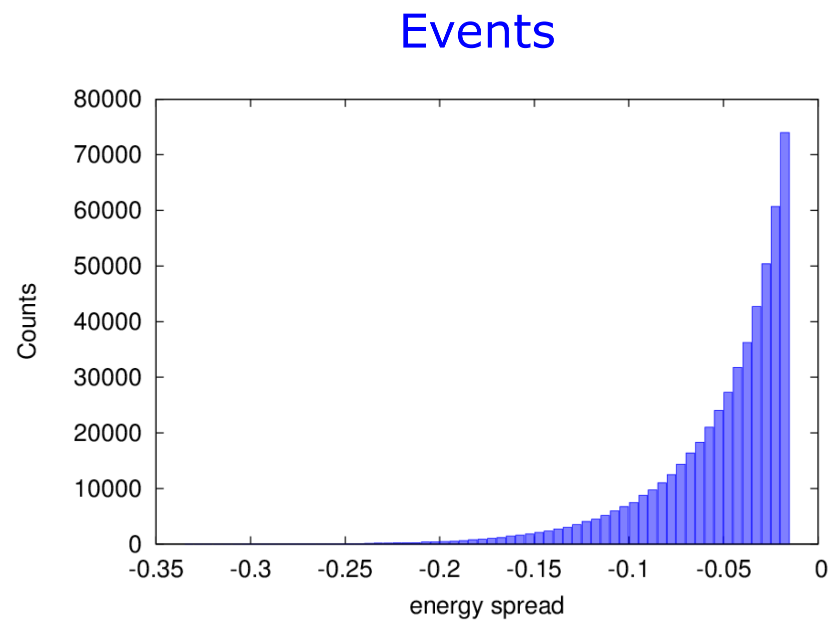




- The lost particles has been reduced to a very low level with RBB collimators, especially in the upstream of the IP, can be accepted by the detector.
- Although the beam loss in the downstream of the IP is still remained, the radiation damage and the detector background are not serious, since the direction is leaving the detector.

Beam-Thermal photon scattering in Higgs

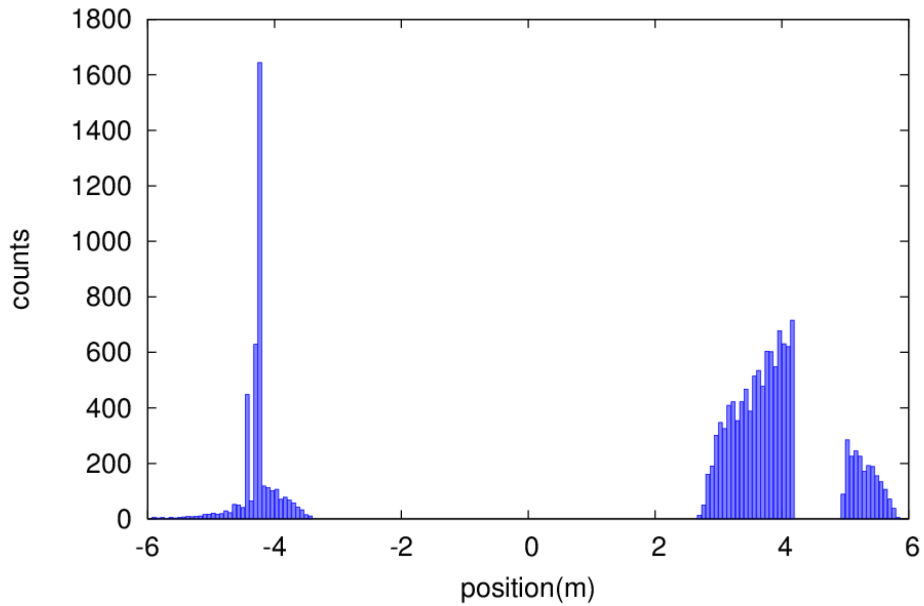




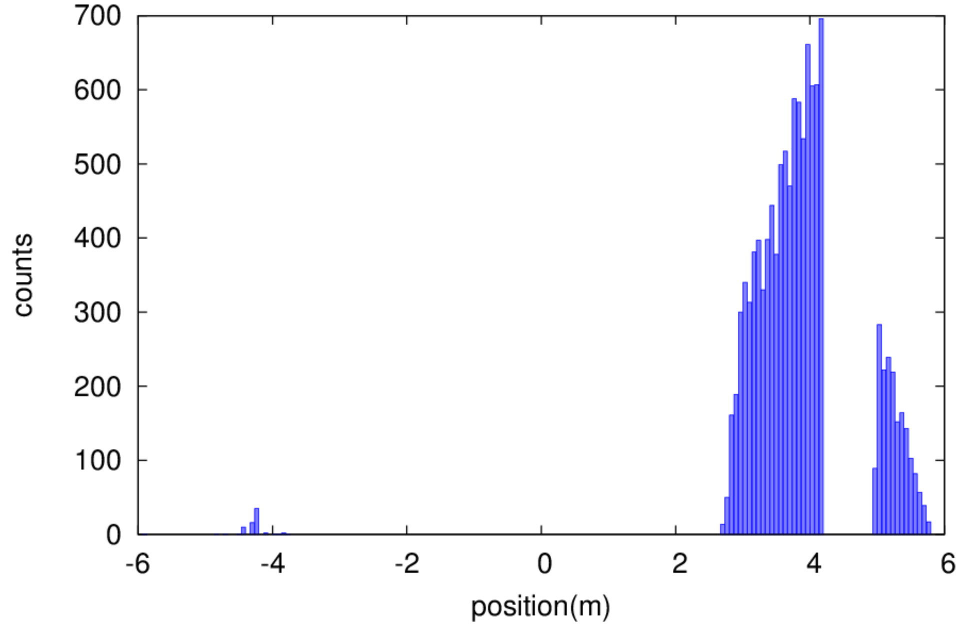
- According to the off-momentum dynamic aperture after optimizing the CEPC lattice, and considering the beam-beam effect and errors, the energy acceptance of CEPC is about 1.5%.
- When the energy acceptance is 1.5%, the beam-thermal photons scattering lifetime is about 50.7 hours.
- Generate ~ 100000 particles.

Beam-Thermal photon scattering loss

Without collimators



With collimators



- The lost particles has gone with RBB collimators in the upstream of the IP, can be accepted by the detector.
- Although the beam loss in the downstream of the IP is still remained, the radiation damage and the detector background are not serious, since the direction is leaving the detector.

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Collimator design in ARC for Z

- Beam stay clear region: 18 σ_x+3mm, 22 σ_y+3mm
- Impedance requirement: slope angle of collimator < 0.1
- To shield big energy spread particles, phase between pair collimators: $\pi/2+n*\pi$
- Collimator design in large dispersion region: $\sigma=\sqrt{\varepsilon\beta + (D_x\sigma_e)^2}$

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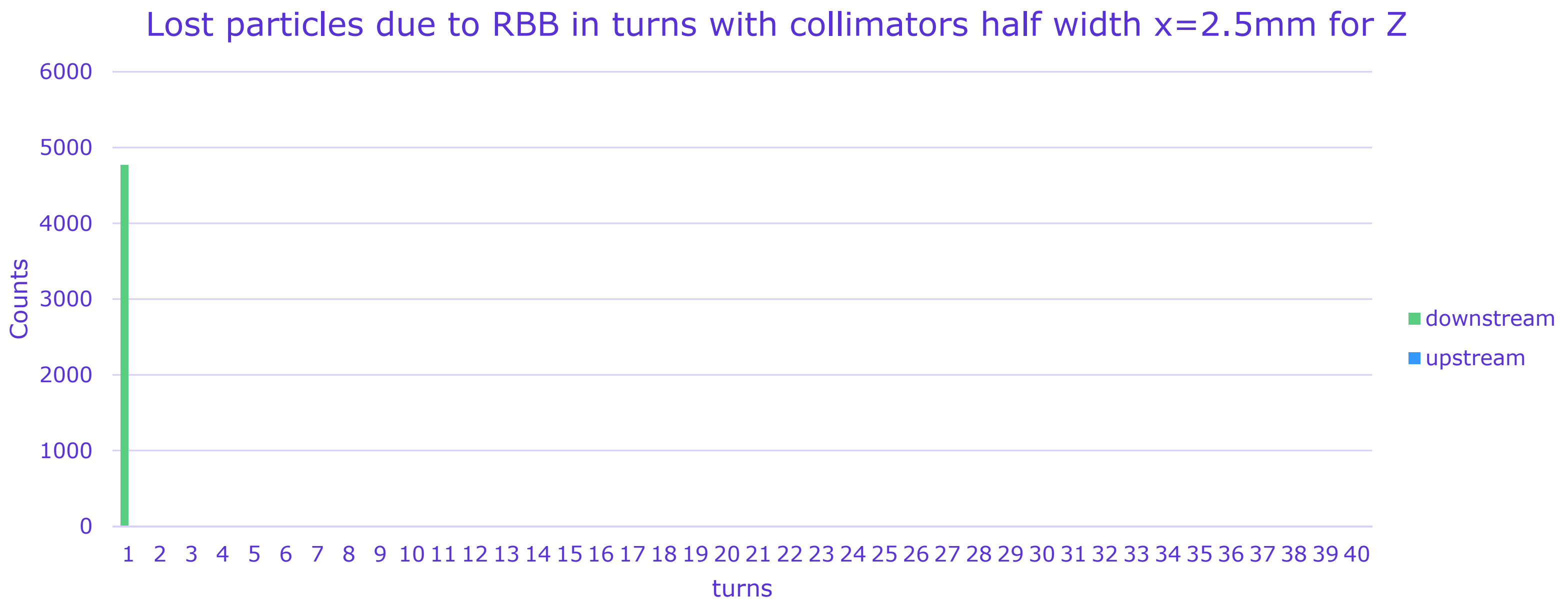
APTX3	D1O.10	1832.52	113.83	0.24	6.876	0.00323	0.83~3.23
APTX4	D1O.14	1901.09	113.83	0.24	7.126	0.00323	0.83~3.23

- Although Z lattice is the same as the one in higgs, the emittance is about 7 times lower. So BSC is smaller.
- According to the off-momentum dynamic aperture after optimizing the CEPC lattice, and considering the beam-beam effect and errors, the energy acceptance is about 1.0%.

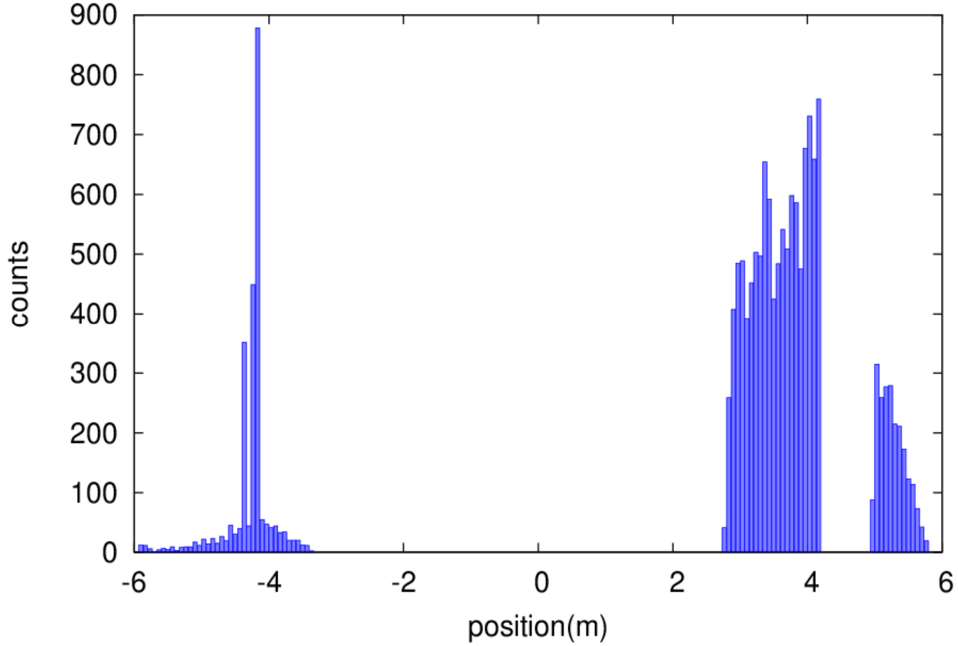
RBB loss with collimators for Z



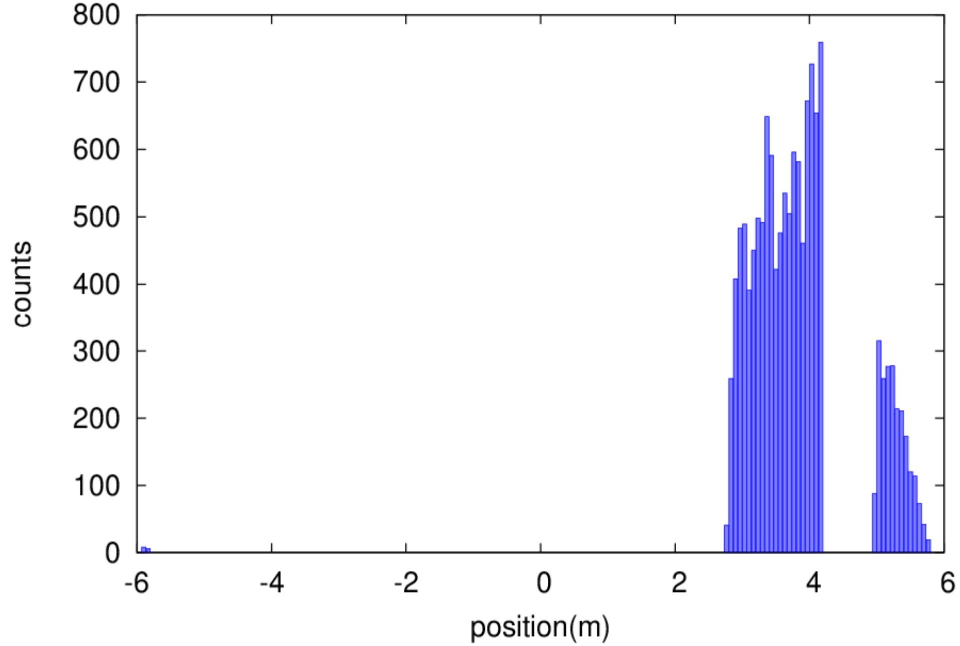
- No beamstrahlung in Z
- horizontal collimator half width 2.5mm($17\sigma_x$)
- The collimators will not have effect on the beam quantum lifetime.
- The lost particles has been reduced to a very low level with the system of collimators, especially in the upstream of the IP.
- Although the beam loss in the downstream of the IP is still pretty large in the first turn tracking, the radiation damage and the detector background are not as serious as the loss rate for the relative small flying angle to the ideal orbit.

Beam-Gas bremsstrahlung in Z

Without collimators

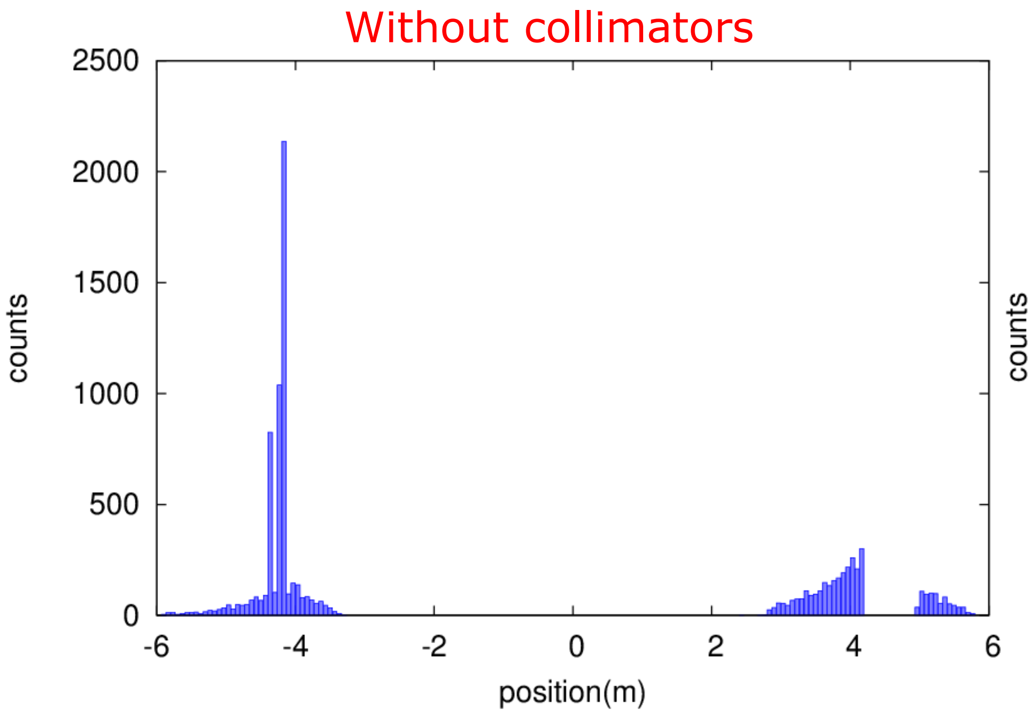


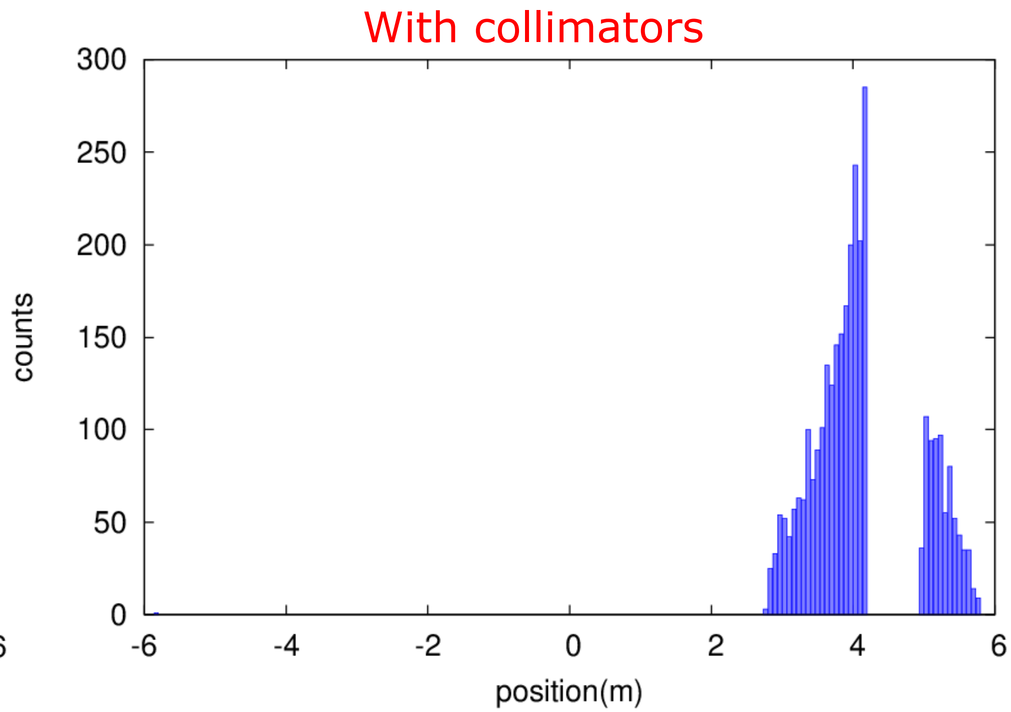
With collimators



- Beam-Gas bremsstrahlung is important effect due to beam lifetime caused by it ~ 57.26 hours.
- With collimators design half width x=2.5mm, the beam loss caused by beam-gas bremsstrahlung has disappeared in upstream of the IP. Although the beam loss in the downstream of the IP is still pretty large in the first turn tracking, the radiation damage and the detector background are not as serious as the direction is leaving the detector.

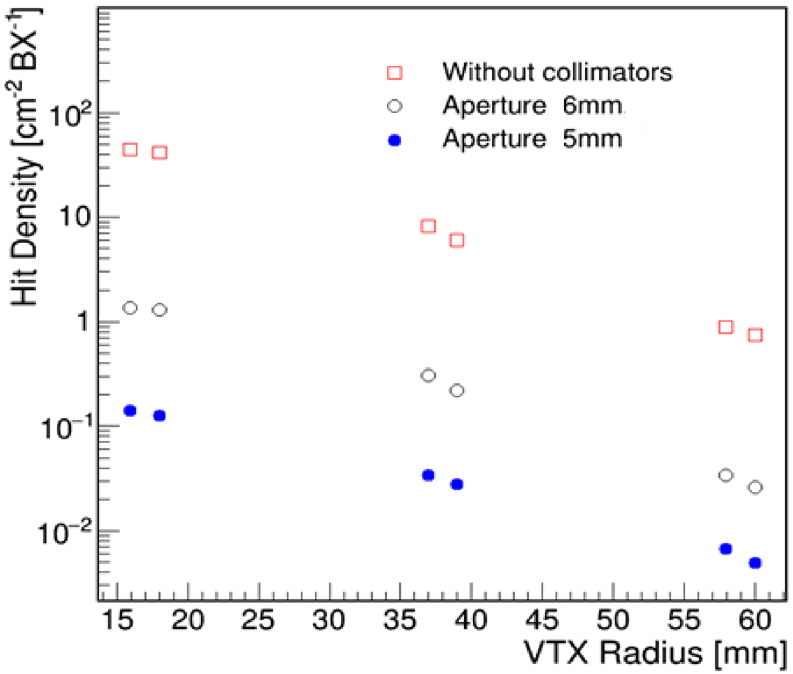
Beam thermal photon scattering in Z





- Beam thermal photon scattering is important effect due to beam lifetime caused by it ~ 70.17 hours.
- With collimators design half width x=2.5mm, the beam loss caused by beam thermal photon scattering has disappeared in upstream of the IP. Although the beam loss in the downstream of the IP is still pretty large in the first turn tracking, the radiation damage and the detector background are not as serious as the direction is leaving the detector.

Hit Density at VTX



- The level of the beam induced backgrounds are evaluated by the hit density at the vertex detector. ~ 1e+7 events input.
- The event rate with collimators is acceptable for the CEPC detector for beam loss particles.
- Requirement from detector: hit density should be smaller than a few hits/cm^2/BX.

Summary

- Beam lifetime of CEPC double ring scheme is evaluated.
- The most importance beam loss background is radiative Bhabha scattering and beamstrahlung.
- Beam loss background in the upstream of multi-turn tracking seems serious, but with two pairs of horizontal collimators which are in the upstream and downstream ARC respectively, beam loss have disappeared in the upstream of IP for both Higgs and Z factory.
- Collimators are designed in the ARC which is about 2km far from the IP to avoid other backgrounds generation.
- The event rate with collimators is acceptable for the CEPC detector for beam loss particles.

Thanks