Institute of High Energy Physics Chinese Academy of Sciences

HKUST Jockey Club Institute for Advanced Study

THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

CEPC MDI

Sha Bai

On behalf of the MDI group and Accelerator Physics group

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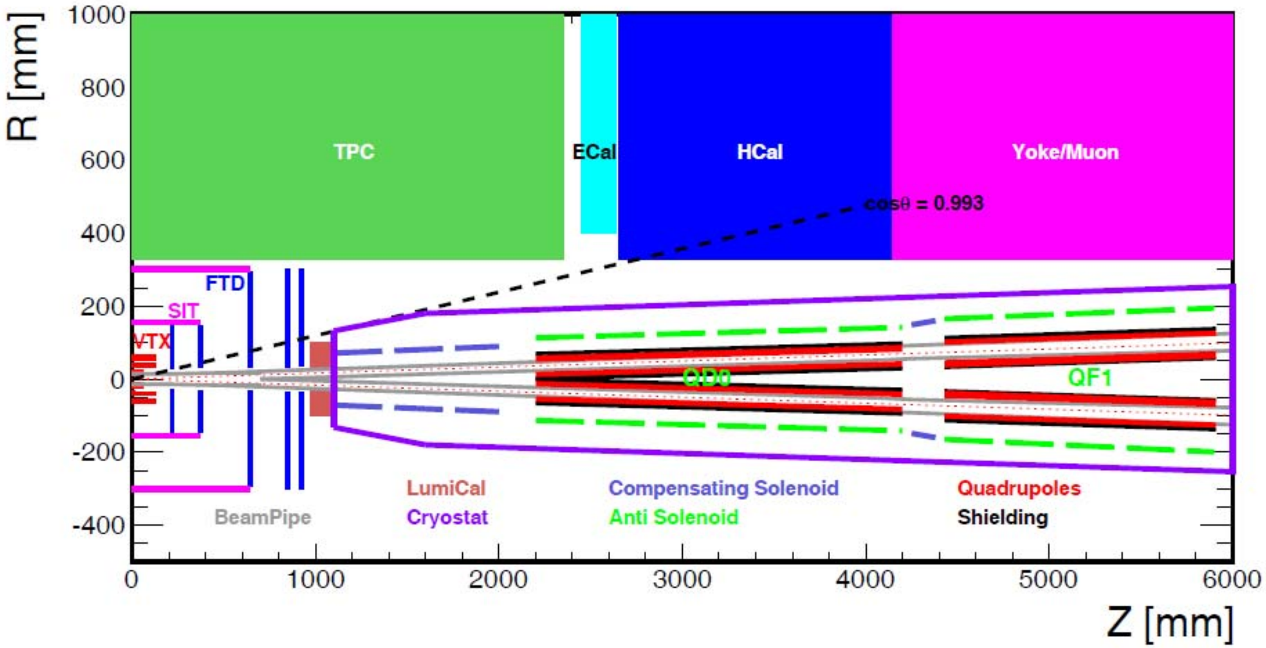
Outline

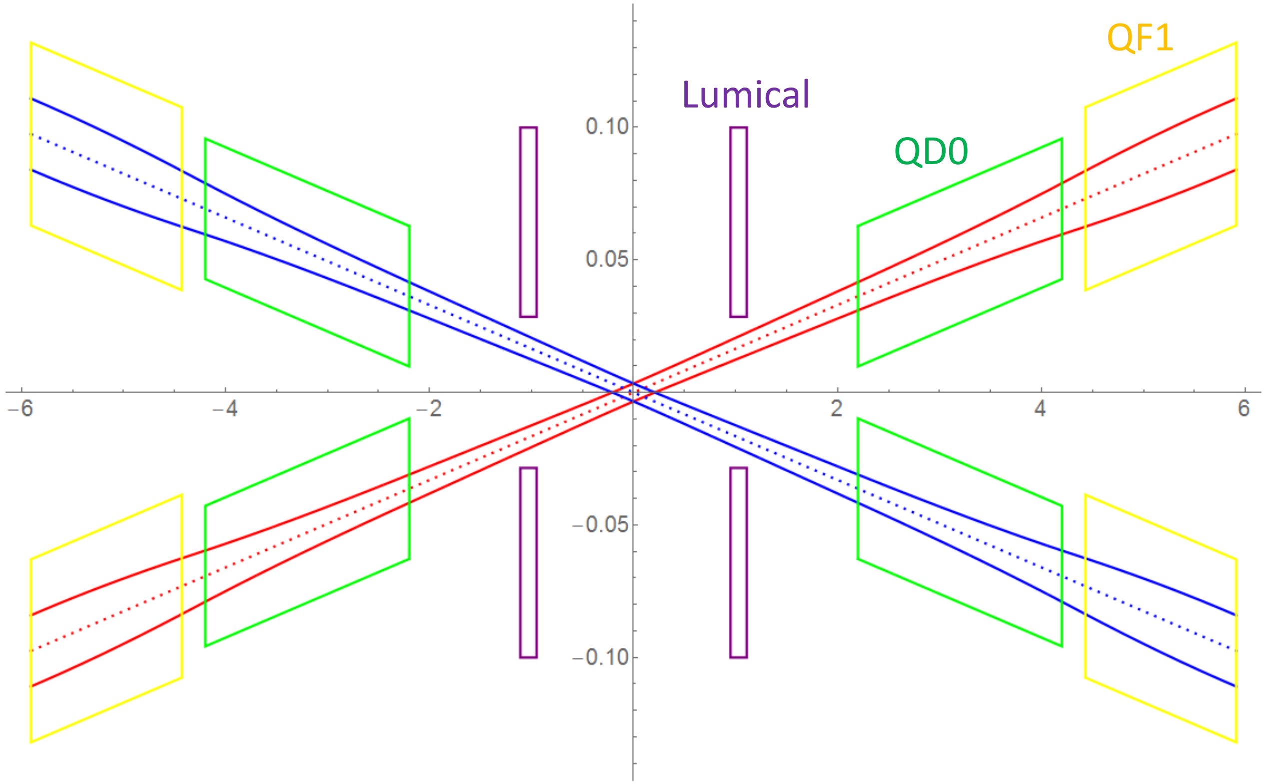
- MDI layout
- IR superconducting magnets
- Solenoid compensation
- Beam pipe
- Synchrotron radiation
- Beam loss backgrounds
- Collimator
- Summary

MDI layout



- The Machine Detector Interface of CEPC double ring scheme is about ±7m long from the IP.
- The CEPC detector superconducting solenoid with 3 T magnetic field and the length of 7.6m.
- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993.
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m
- Lumical will be installed in longitudinal 0.95~1.11m, with inner radius 28.5mm and outer radius 100mm.

Beam stay clear region



According to the considerations of injection and beam tail effect after collision, CEPC IR beam stay clear region are defined as:

$BSC\_x = \pm(18\sigma_x + 3mm)$

$BSC\_y = \pm(22\sigma_y + 3mm)$

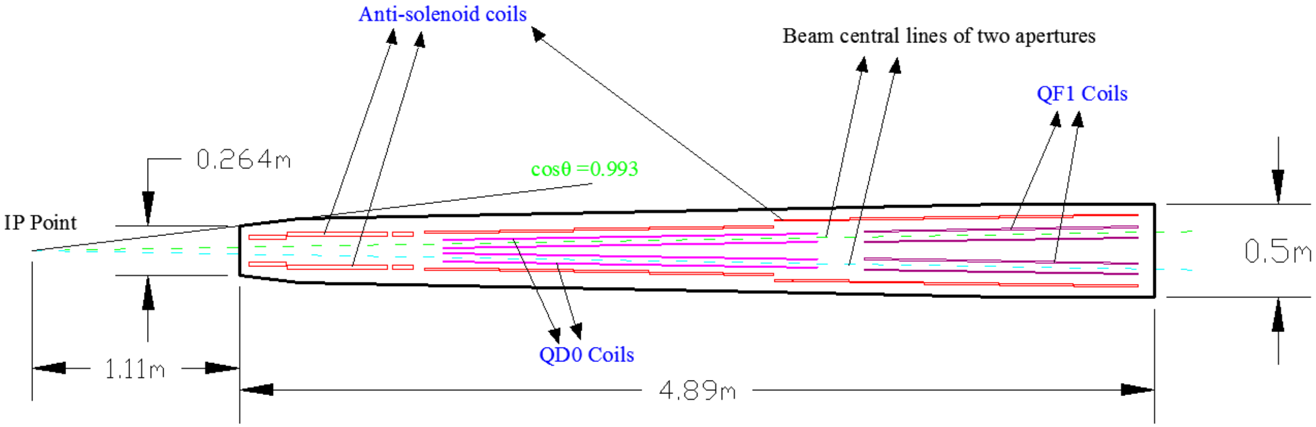
QD0/QF1 physics design parameters

β_y*=1.5mm

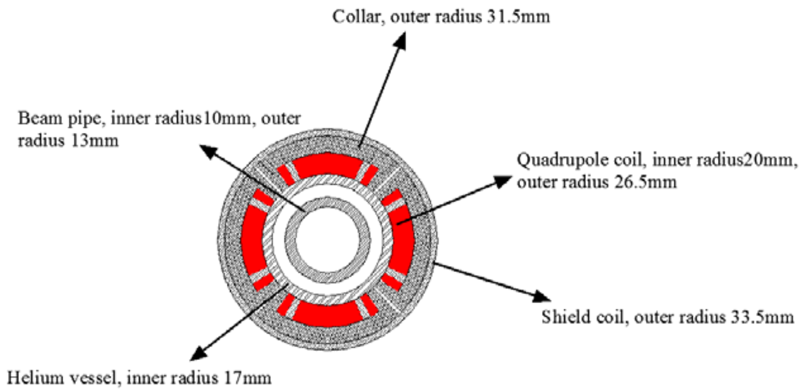
QD0	Horizontal BSC 2（18σ_x+3）	Vertical BSC 2（22σ_y+3）	e+e- beam center distance
Entrance	10.65 mm	14.69 mm	72.61 mm
Middle	13.65 mm	16.99 mm	105.61 mm
Exit	19.32 mm	15.67 mm	138.61 mm
Good field region	Horizontal 19.32 mm; Vertical 17.03 mm		
Effective length	2 m		
Distance from IP	2.2 m		
Gradient	136 T/m		

QF1	Horizontal BSC 2（18σ_x+3）	Vertical BSC 2（22σ_y+3）	e+e- beam center distance
Entrance	21.06 mm	14.96 mm	146.20 mm
Middle	25.36 mm	13.32 mm	170.30 mm
Exit	26.85 mm	12.75 mm	195.05 mm
Good field region	Horizontal 26.85 mm; Vertical 14.96 mm		
Effective length	1.48 m		
Distance from IP	4.43 m		
Gradient	110 T/m		

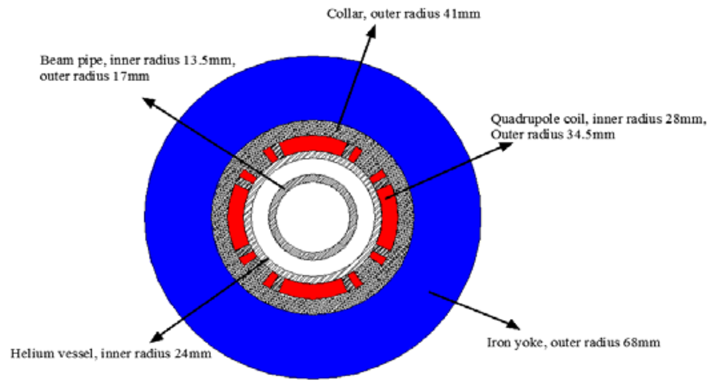
IR superconducting magnets



- Both of QD0 and QF1 are double aperture superconducting magnets.
- QD0/QF1 and anti-solenoid are all in a cryogenics system.
- QD0/QF1 peak field in coil 3.2T/3.8T.

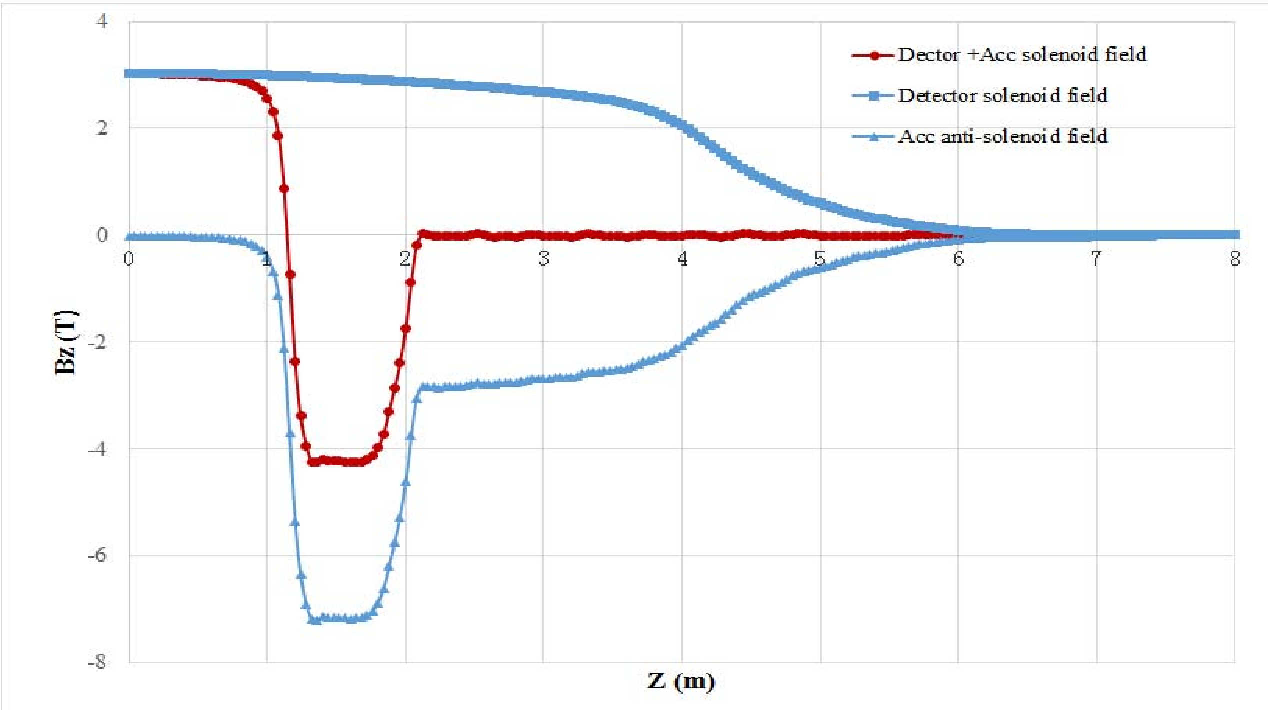


Single aperture QD0



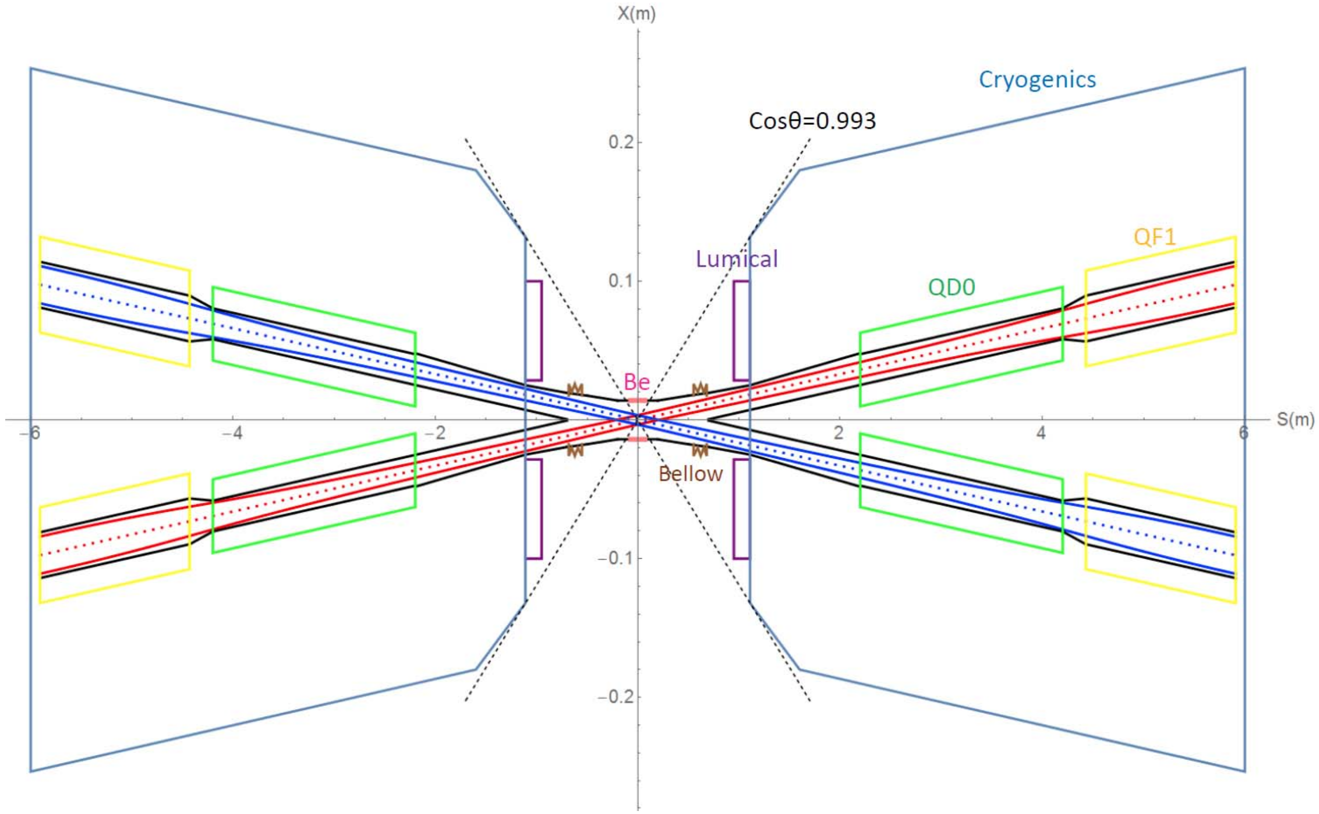
Single aperture QF1

Solenoid compensation



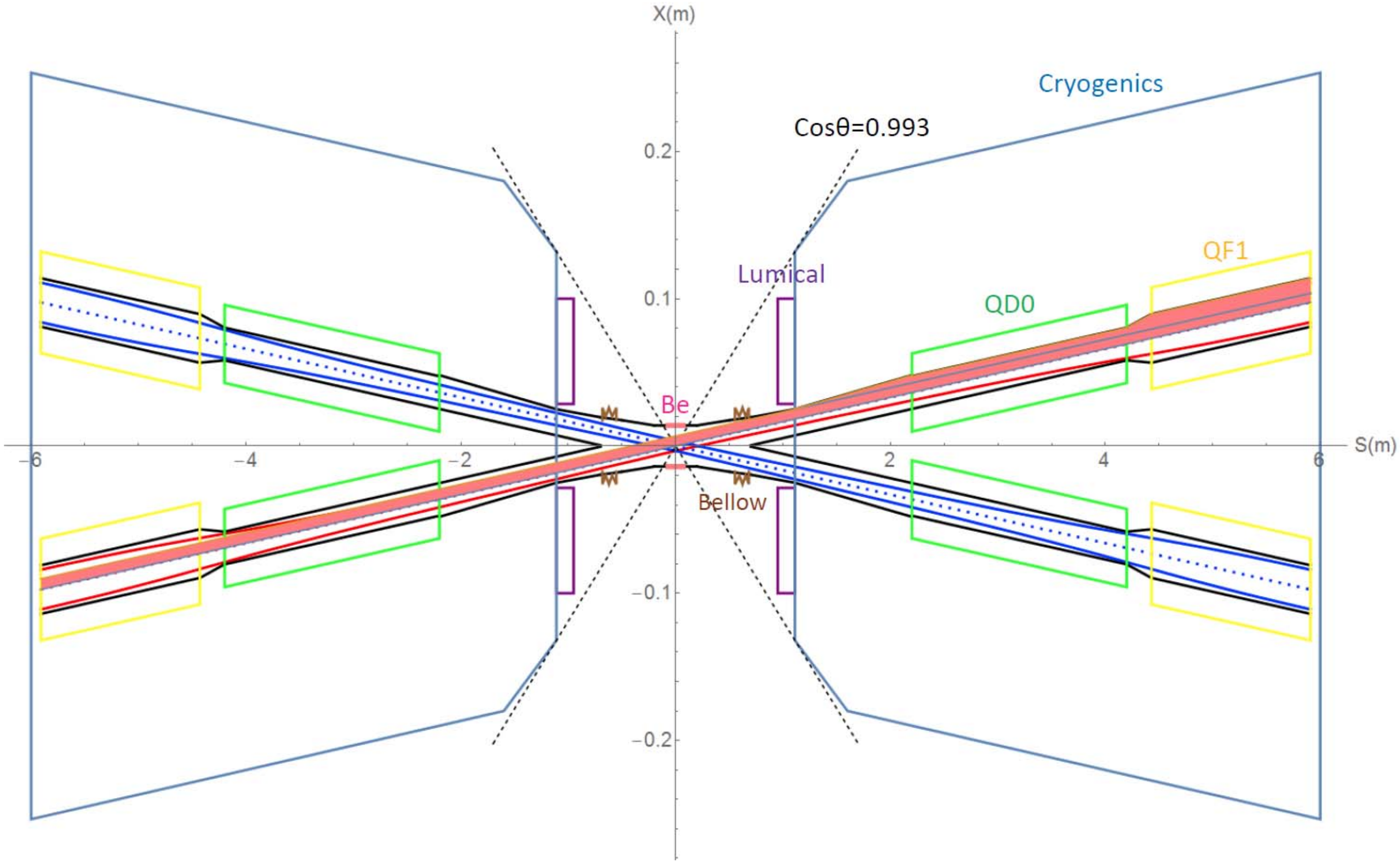
- Anti-solenoids are designed to compensate the solenoid field from the detector.
- The integral longitudinal field $\int B_z ds$ within 0~2.12m is 0 and Bz is less than 300Gauss after 2.12m away from the IP.

IR beam pipe



- The inner diameter of the beryllium pipe ~28mm. The length of beryllium pipe is ±7cm in longitudinal.
- Due to detector beamstrahlung incoherent pairs, beam pipe in between 0.2~0.5m should be changed into cone.
- The connection from single pipe to double pipe is realized by a bellow at 0.5~0.7m.
- From the bellow to the entrance of the quadrupole, the beam pipe is special shaped with the cross section at ±0.7m in longitudinal for installing cooling and bellows.
- For the beam pipe within the final doublet quadrupoles, room temperature beam pipe has to be adopted.

SR from last B magnet upstream

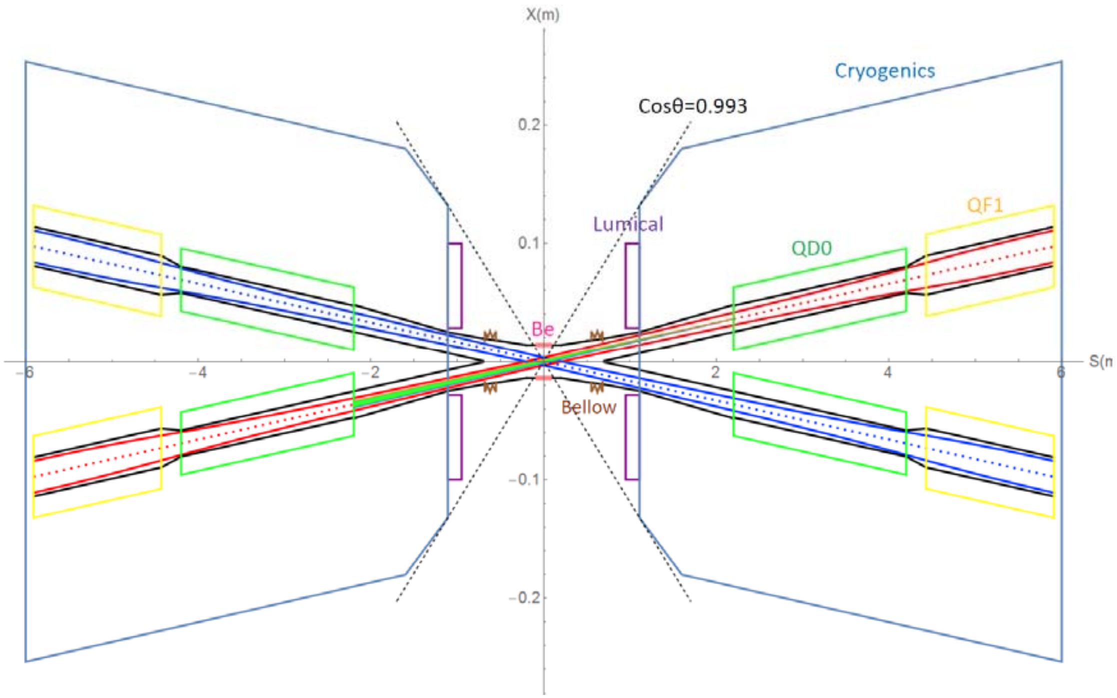


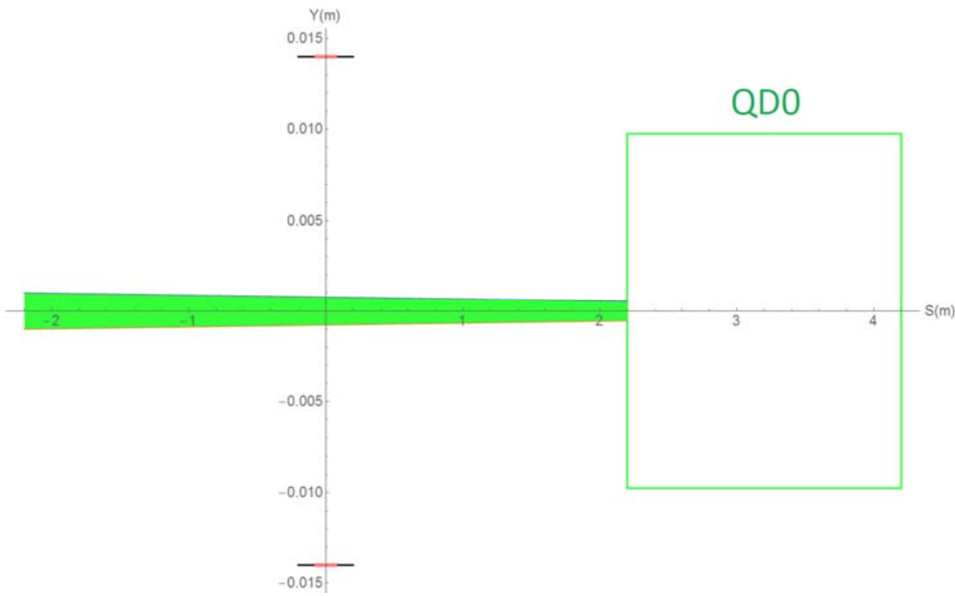
- Last bending magnet generates a fan of SR with power 60W contributed by e+ will go through the IP. The critical energy of photons is about 45keV.
- No SR hits directly on the detector beryllium pipe.
- The synchrotron radiation generated by electron beam is symmetric with positron beam.

Critical energy of bending magnets in IR

Name	length	angle	Distance from IP	Cirtical energy
BMV01IRU	93.38	-0.0011	67.66	45keV
BMV02IRU	68.95	-0.00156	168.99	86.7keV
BMV03IRU	68.95	-0.00212	239.94	117.9keV
BMV1IRU	68.95	0	312.99	0
BMV2IRU	68.95	-0.00352	383.94	195.7keV
BMV3IRU	68.95	-0.00352	456.99	195.7keV
BMV01IRD	60.97	0.00154	46.06	97keV
BMV02IRD	44.2	0.00259	116.07	224.6keV
BMV03IRD	44.2	0.00311	162.27	269.7keV
BMV1IRD	44.2	0	210.57	0
BMV2IRD	44.2	0.00537	256.77	465.7keV
BMV3IRD	44.2	0.00537	305.07	465.7keV

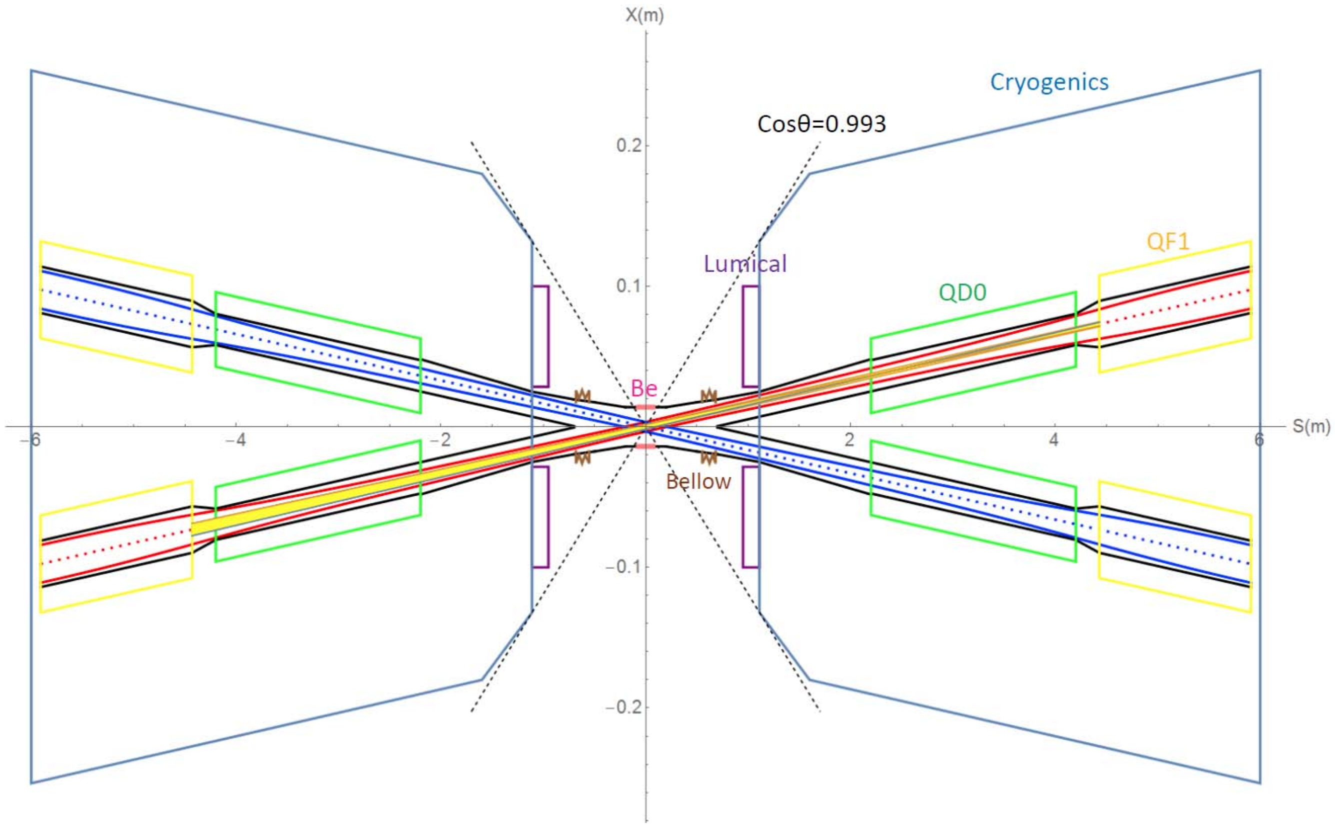
SR from QD0 in horizontal and vertical plane





- SR fans generated by QD0 of particles in 3σ.
- The total SR power generated by the QD0 is 639.3 in horizontal and 165.6W in vertical.
- The critical energy of photons is about 1.3MeV in horizontal and 397keV in vertical.

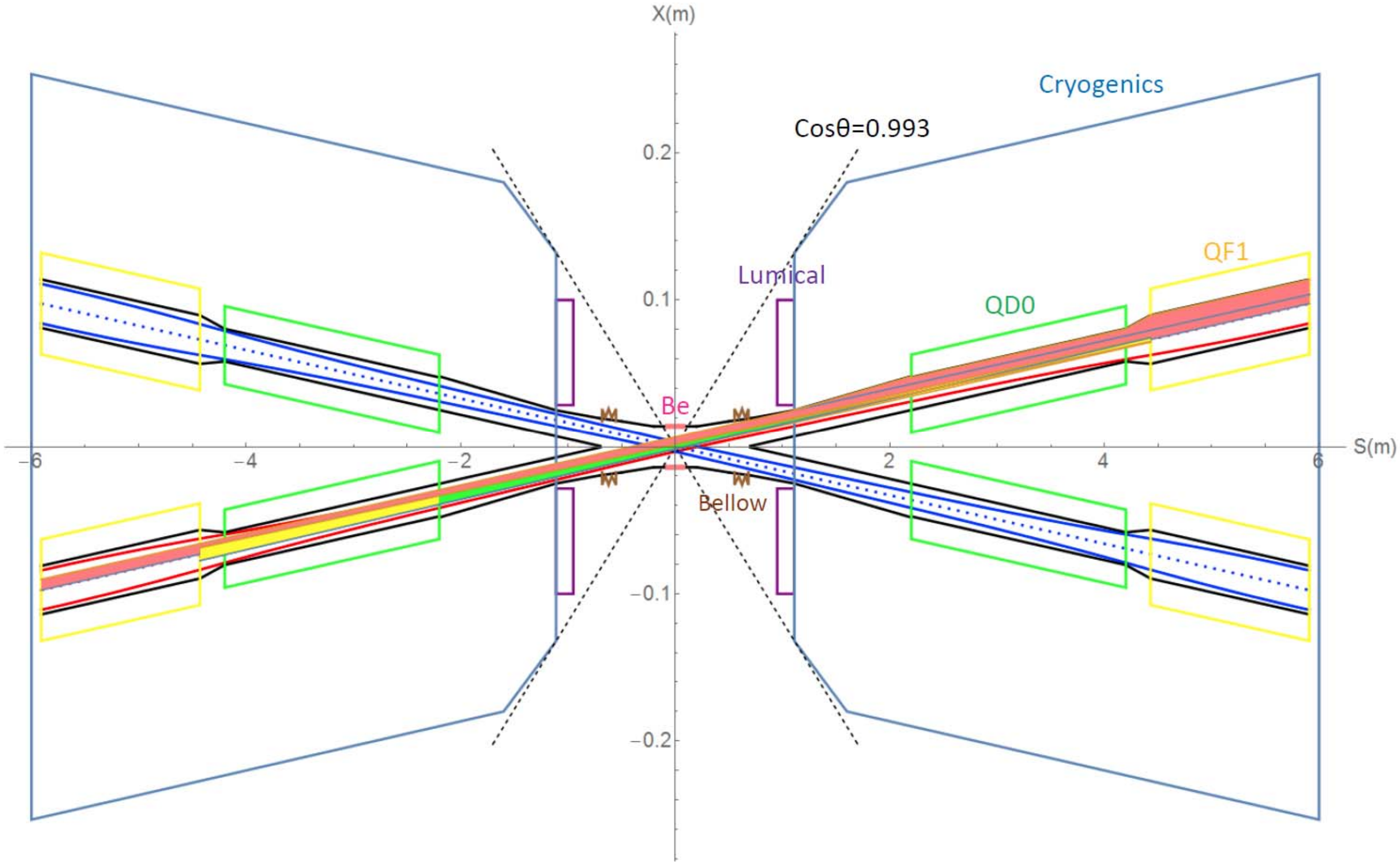
SR from QF1 in horizontal plane



- The total SR power generated by the QF1 magnet is 1567W in horizontal and 42W in vertical.
- The critical energy of photons is about 1.6MeV in Horizontal and 225keV in vertical.
- There is no SR photons within $6\sigma_x$ directly hitting or once-scattering to the detector beam pipe.

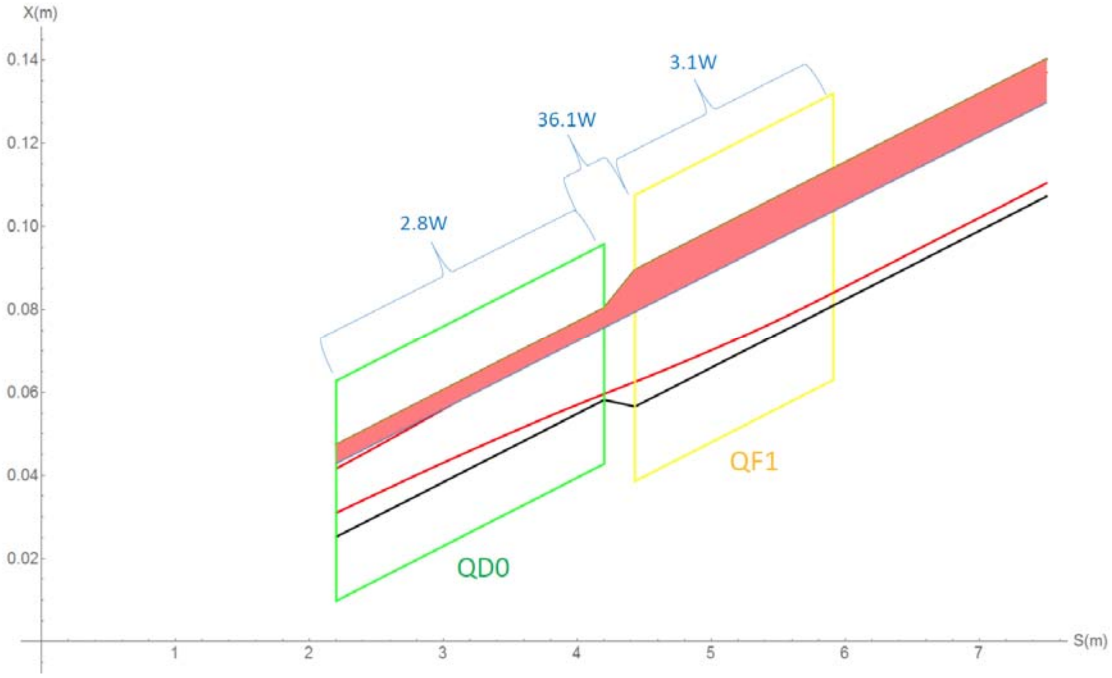
SR from B, FD in horizontal plane

~ last bending magnet upstream of IP and final doublet



The synchrotron radiation in the IR

- “Room temperature” beam pipe and conduction cooled superconducting magnet has to be adopted.

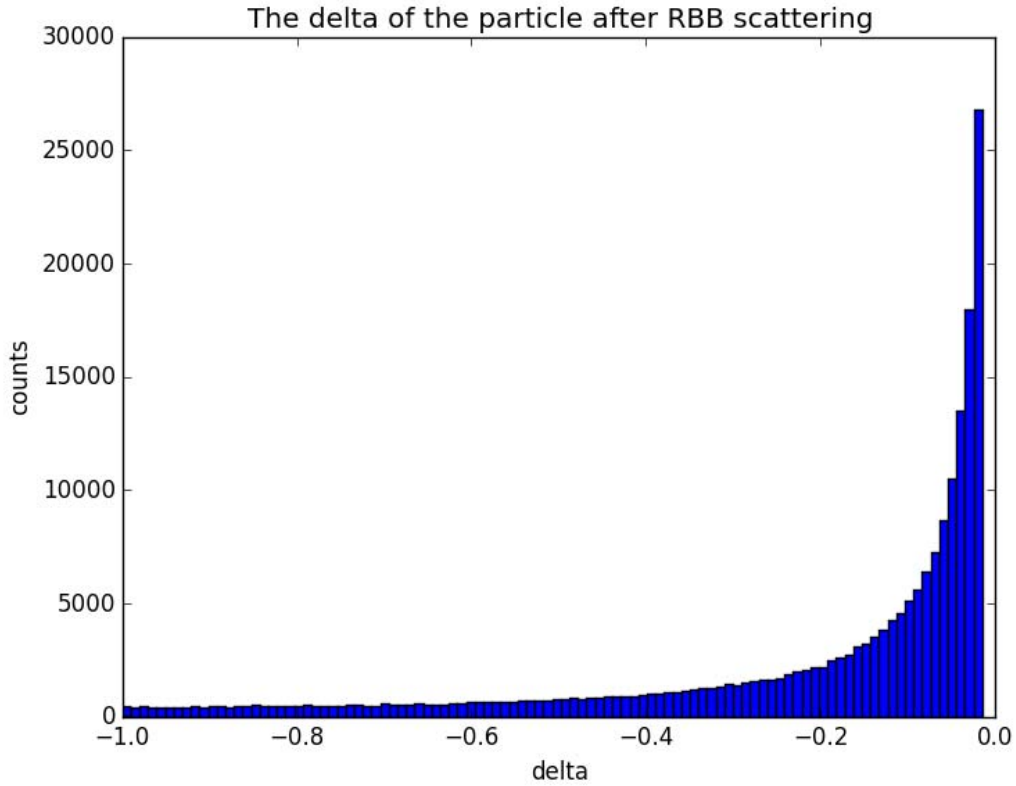


- The synchrotron radiation power within QD0 is 2.8W along 2m, on QF1 is 3.1W along 1.48m. The region between QD0 and QF1 is 36.1 W (0.23m).

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

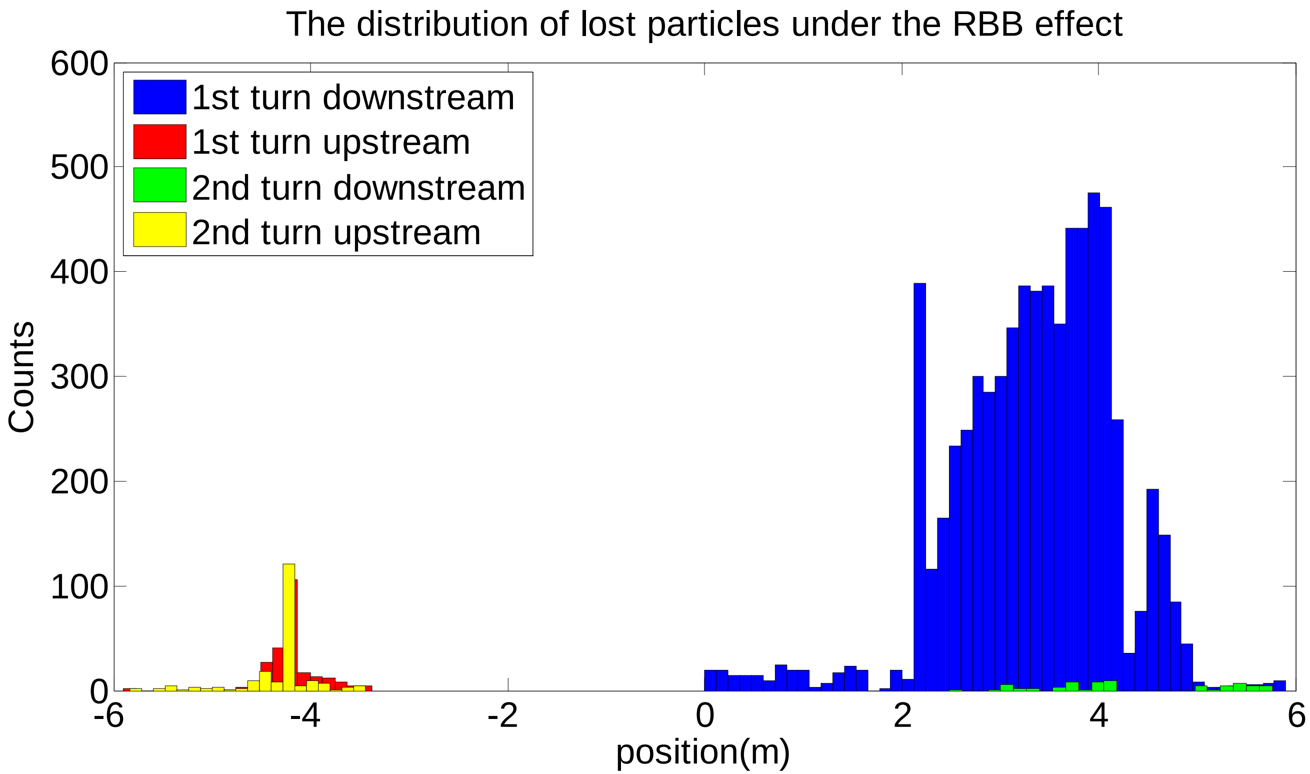


- According to the off-momentum dynamic aperture after optimizing the CEPC lattice, and considering the beam-beam effect and errors, the energy acceptance of CEPC is about 1.5%.
- Radiative Bhabha scattering is simulated by BBBrem or Py_RBB.
- Generate 2e+5 particles.

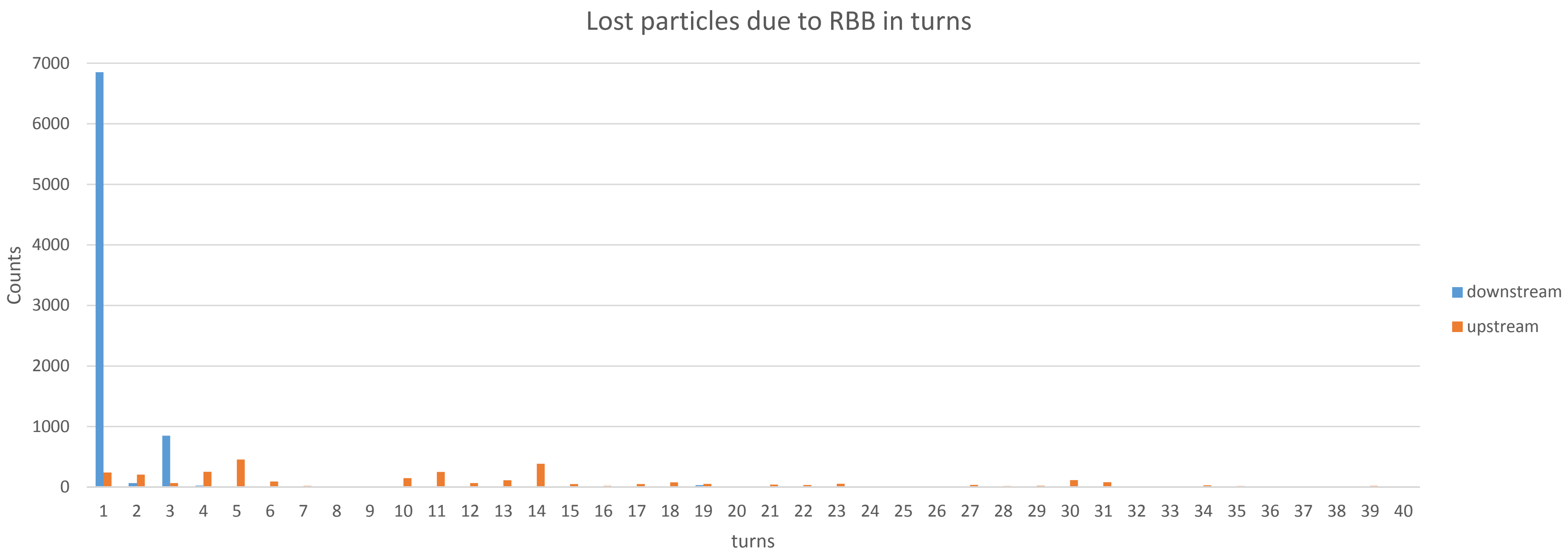
RBB lost particles statistic

~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.

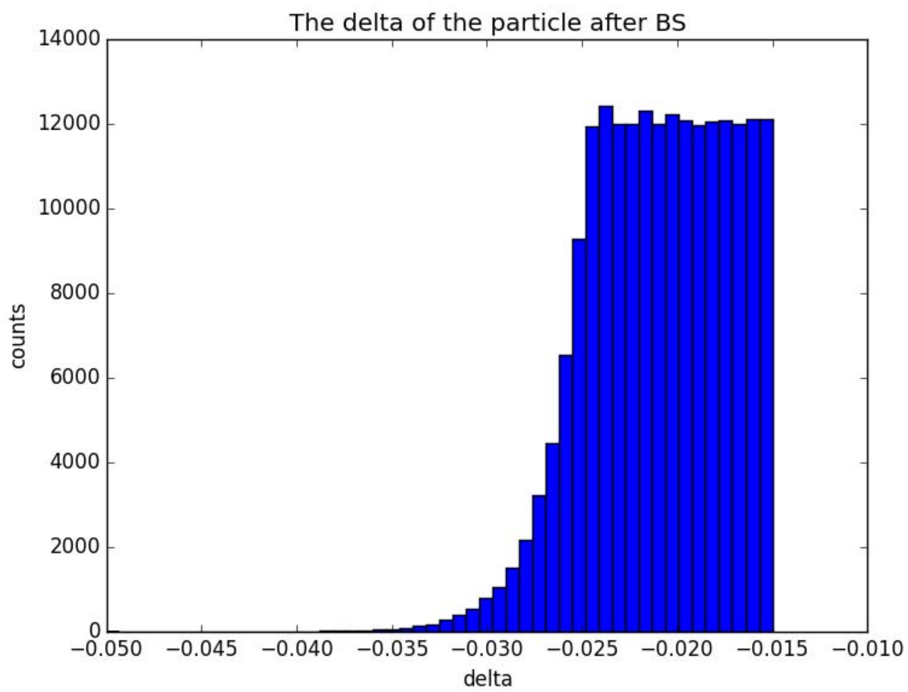


Loss particles due to RBB in turns



- 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.

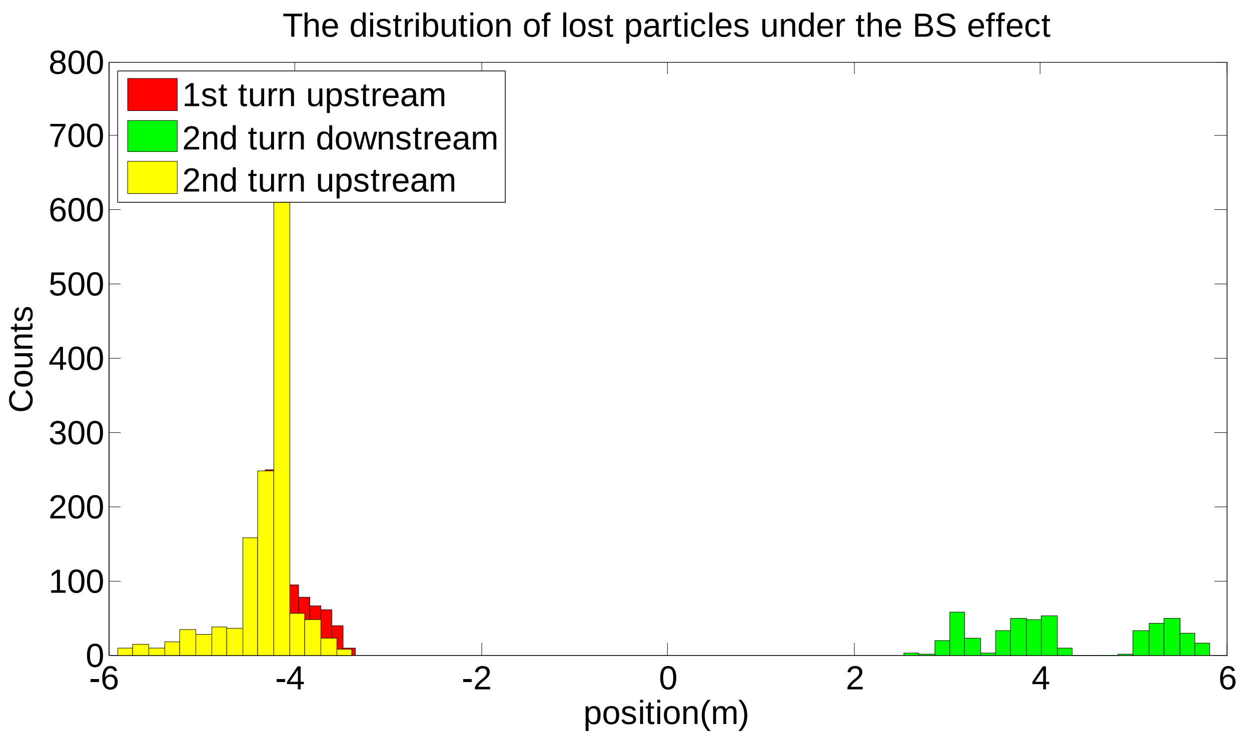
Beamstrahlung events



- Compared with the energy spread of RBB, beamstrahlung effect is increased in exponential growth with energy spread, so most of particles energy spread are distributed in a region close to 1.5%.
- Beamstrahlung events have been generated with Guinea-Pig++ or Py_BS.
- Generate 200000 particles.

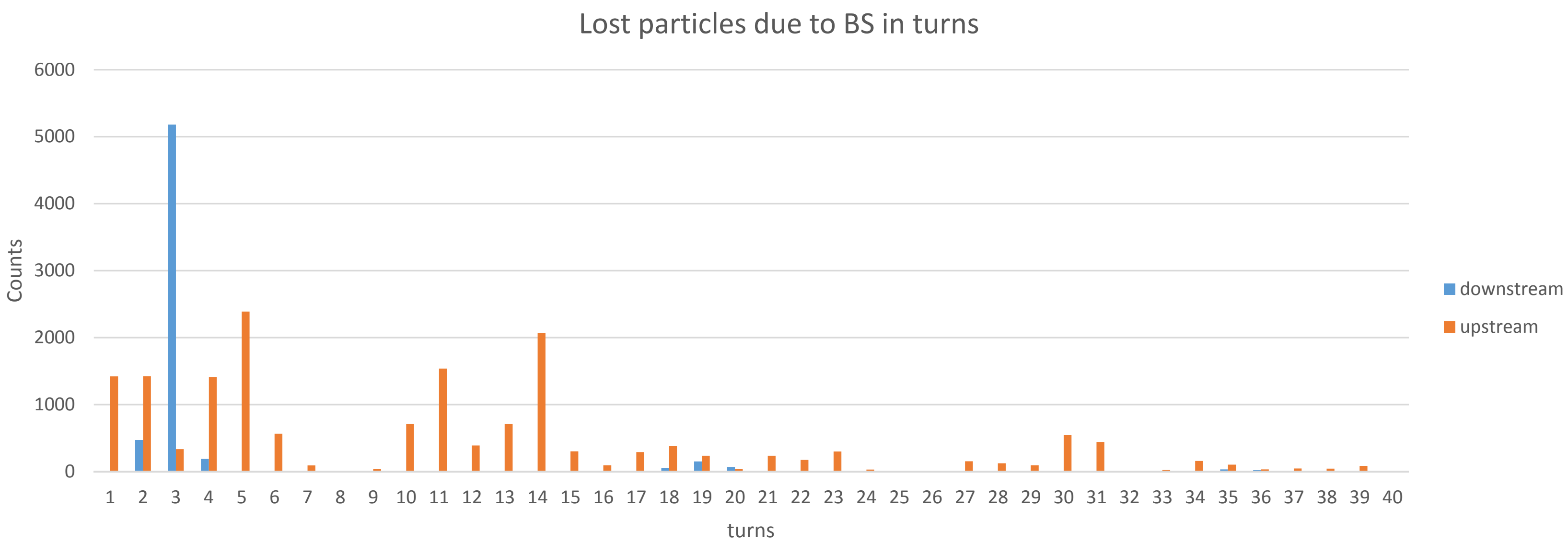
BS lost particles statistic

~first two turns



- 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 turns



- 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.

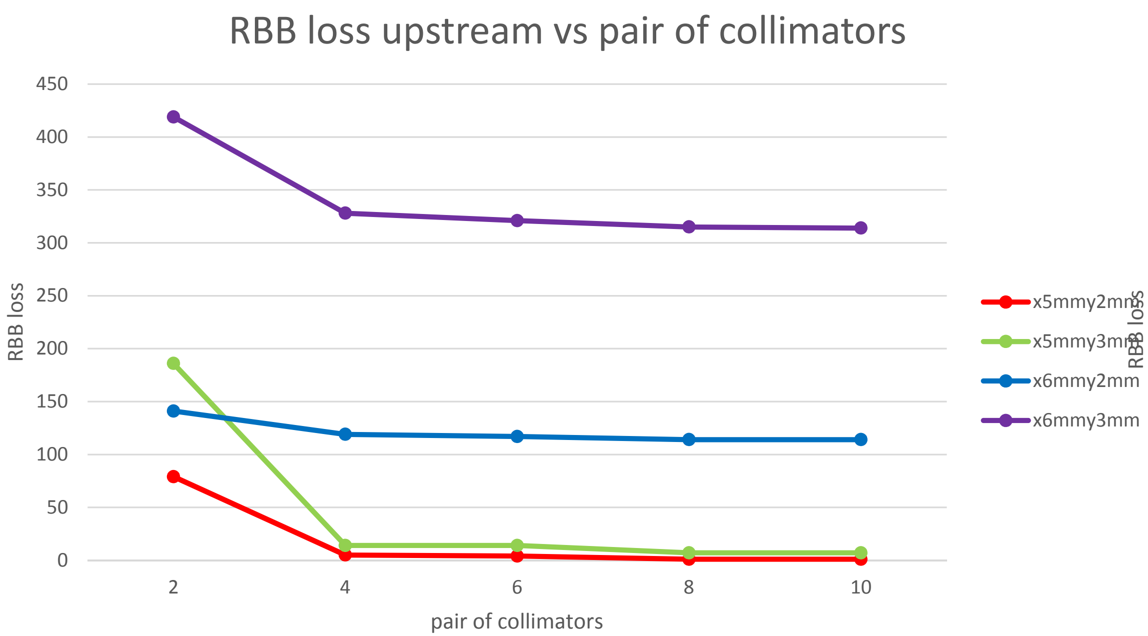
Collimator design in ARC

- 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: $\sigma=\sqrt{\varepsilon\beta + (D_x\sigma_e)^2}$

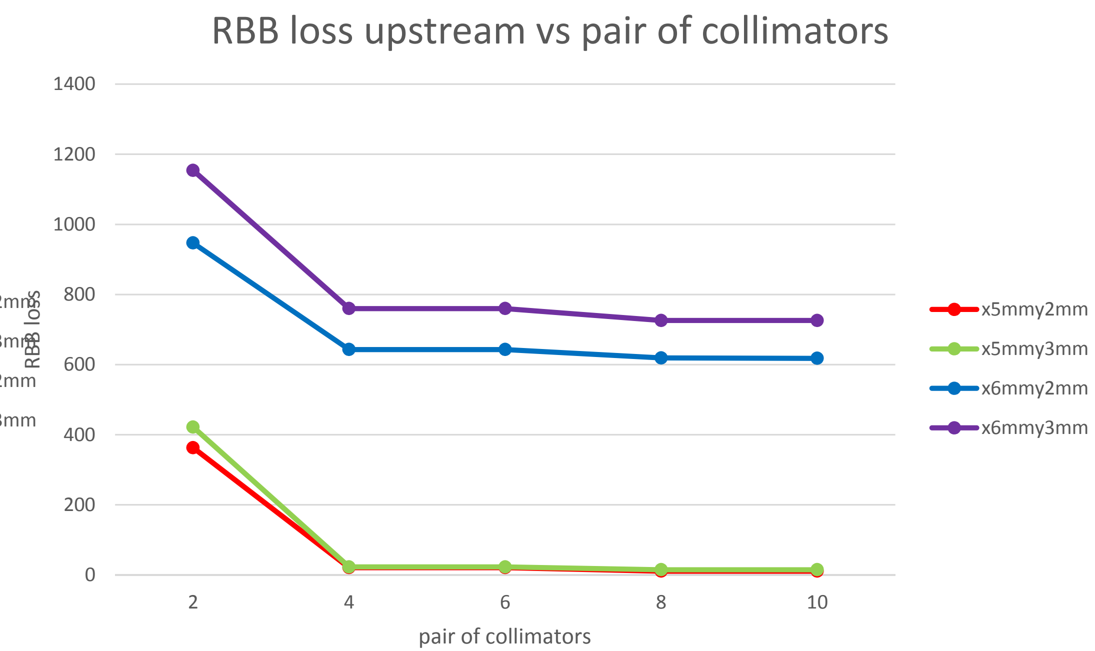
name	Position	Distance to IP/m	Beta function/m	Horizontal Dispersion/m	Phase	BSC/2/m	Range of half width allowed/mm
APTX1	D1I.1884	2413.35	113.83	0.24	355.91	0.00968	1~10
APTX2	D1I.1906	1933.35	113.83	0.24	357.66	0.00968	1~10
APTX3	D1I.1868	2756.21	113.83	0.24	354.66	0.00968	1~10
APTX4	D1I.1878	2550.49	113.83	0.24	355.41	0.00968	1~10
APTY1	D1I.1890	2276.21	20.70	0.24	358.39	0.003348	1~3.5
APTY2	D1I.1900	2070.49	20.70	0.24	359.14	0.003348	1~3.5
APTY3	D1I.1849	3167.62	20.70	0.24	355.14	0.003348	1~3.5
APTY4	D1I.1852	3099.06	20.70	0.24	355.39	0.003348	1~3.5

RBB loss upstream vs pair of collimators

Collimators at big β_y position

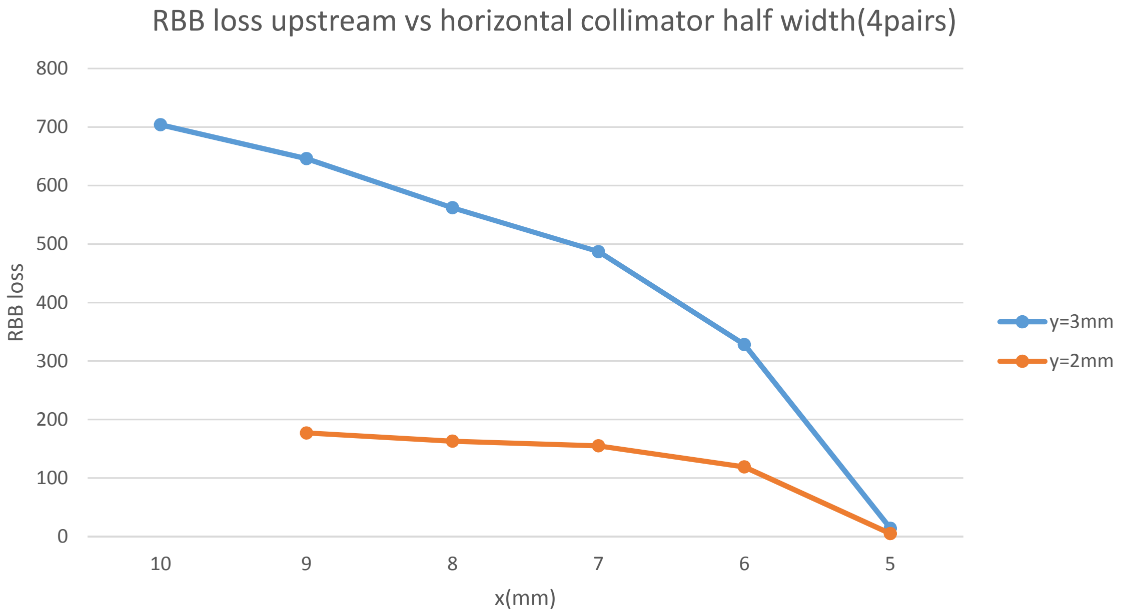


Collimators at small β_y position

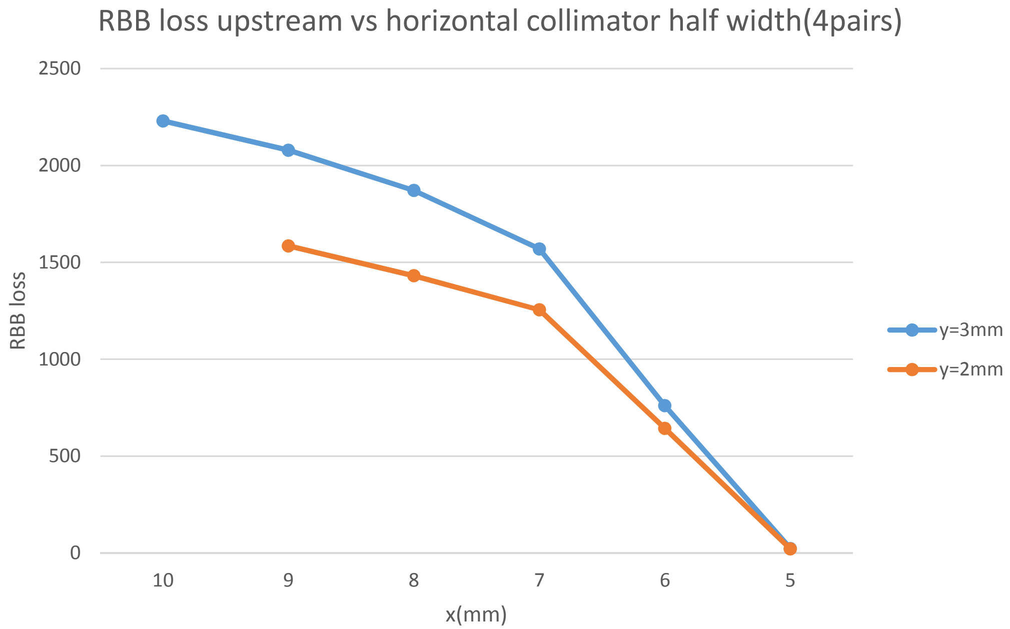


- With 4 pair of collimators, RBB loss upstream with collimators half width x5mmy2mm are much similar with x5mmy3mm case
- RBB loss with collimator put at small β_y positon are much similar with big β_y positon.

RBB loss with horizontal collimator half width



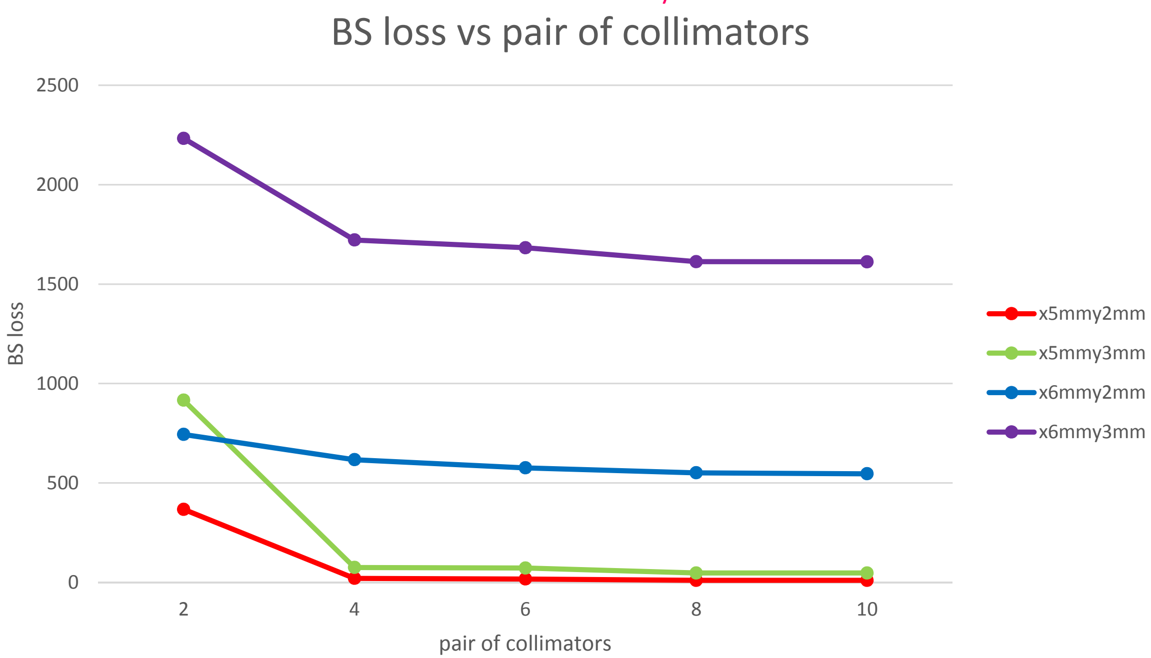
Collimators at big β_y position



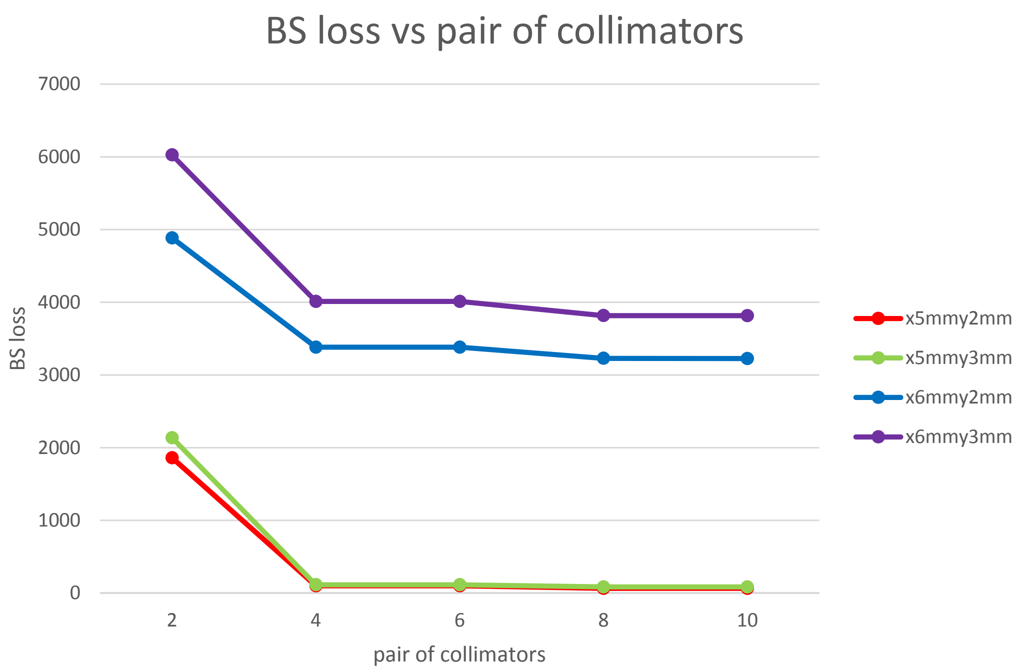
Collimators at small β_y position

BS loss upstream vs pair of collimators

Collimators at big β_y position

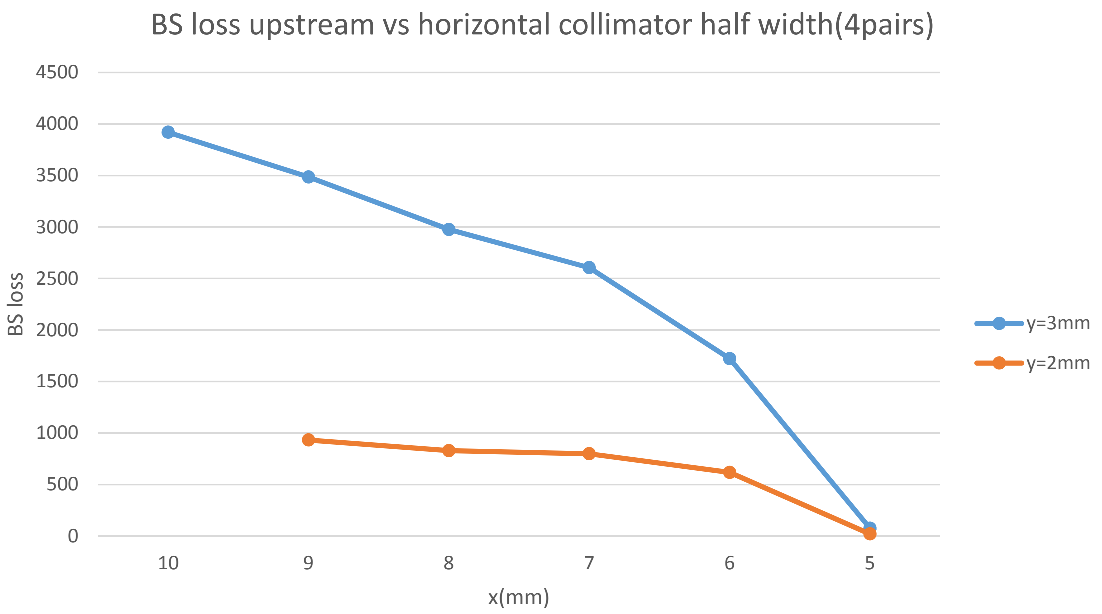


Collimators at small β_y position

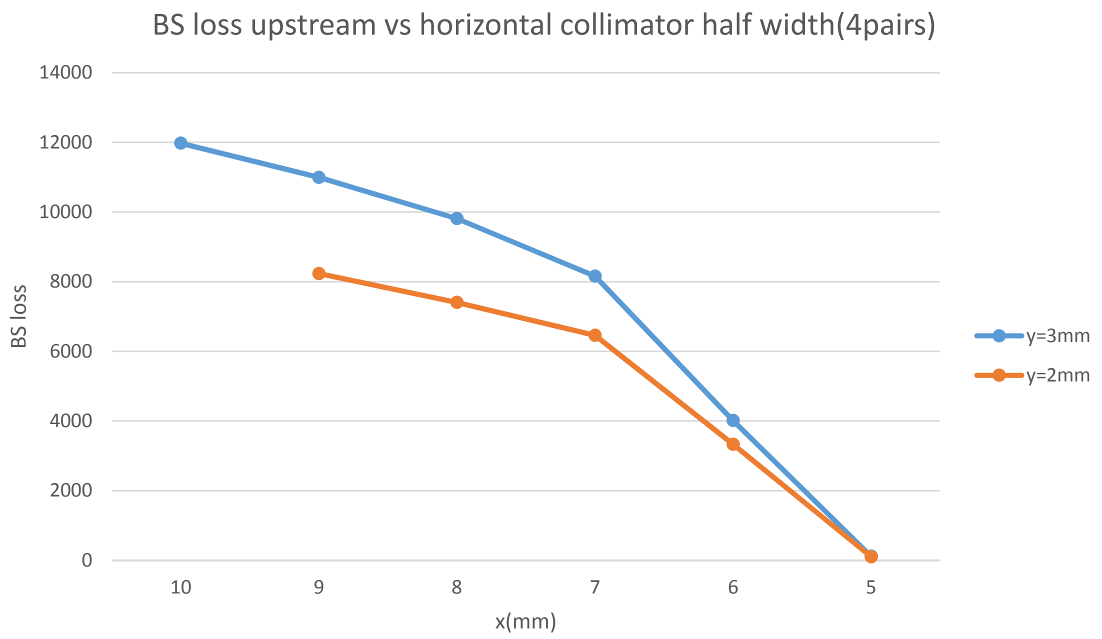


- With 4 pair of collimators, BS loss upstream with collimators half width x5mmy2mm are much similar with x5mmy3mm case
- BS loss with collimator put at small β_y positon are much similar with big β_y positon.

BS loss with horizontal collimator half width

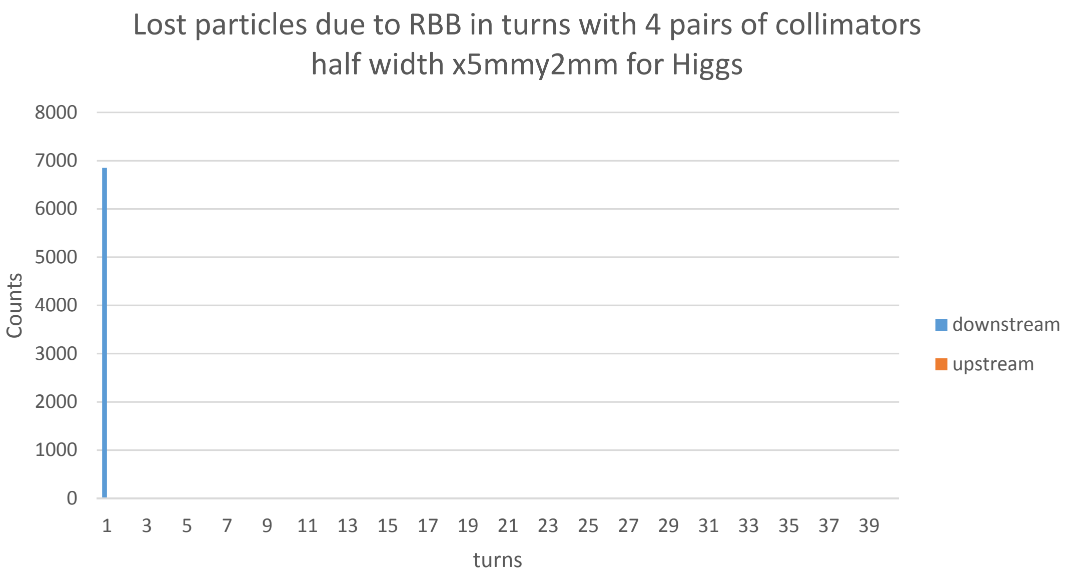


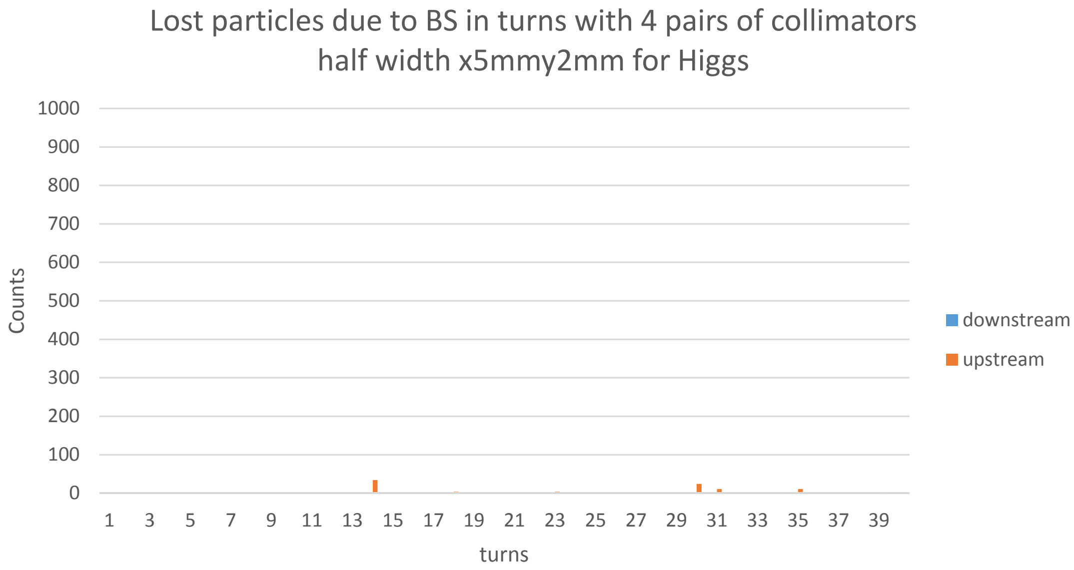
Collimators at big β_y position



Collimators at small β_y position

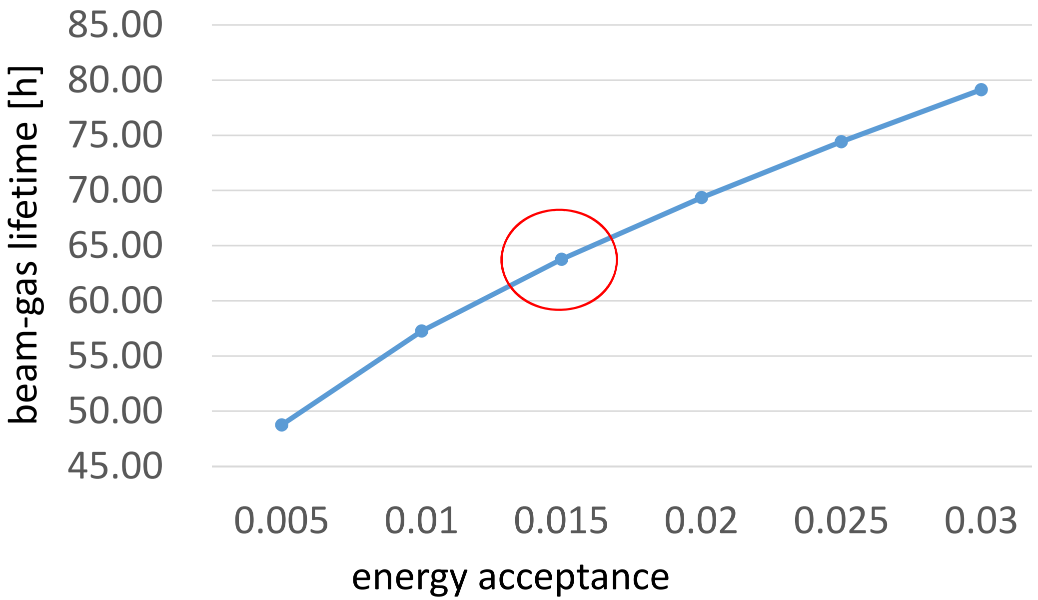
RBB and BS loss with collimators for Higgs

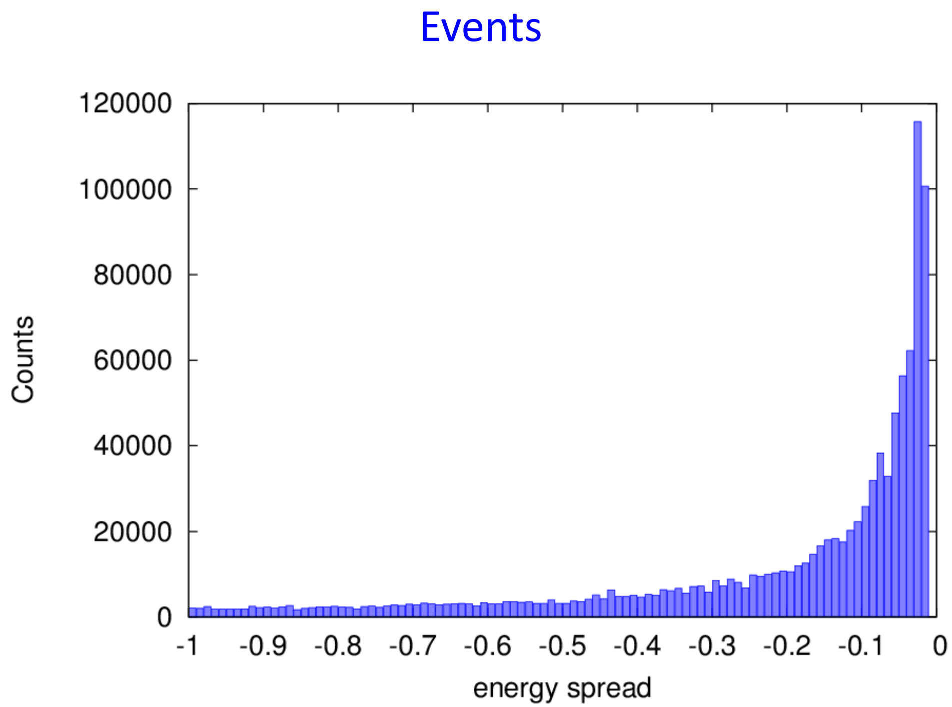




- horizontal collimator half width 5mm($14\sigma_x$), vertical collimator half width 2mm($127\sigma_y$).
- The collimators will not affect the beam quantum lifetime.
- Collimator put at small β_y positon to reduce TMCI.
- The lost particles has been reduced to a very low level with the system of collimators, 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

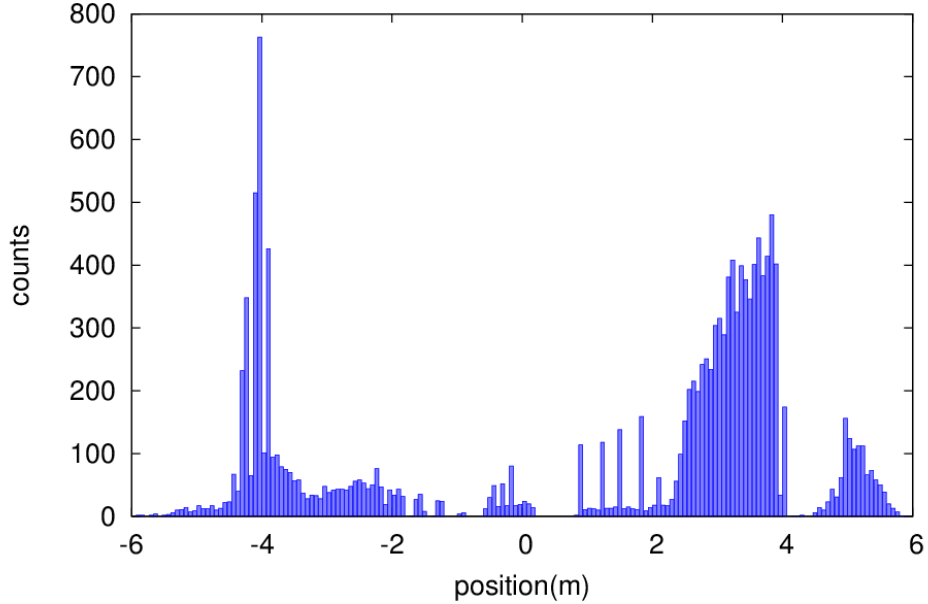




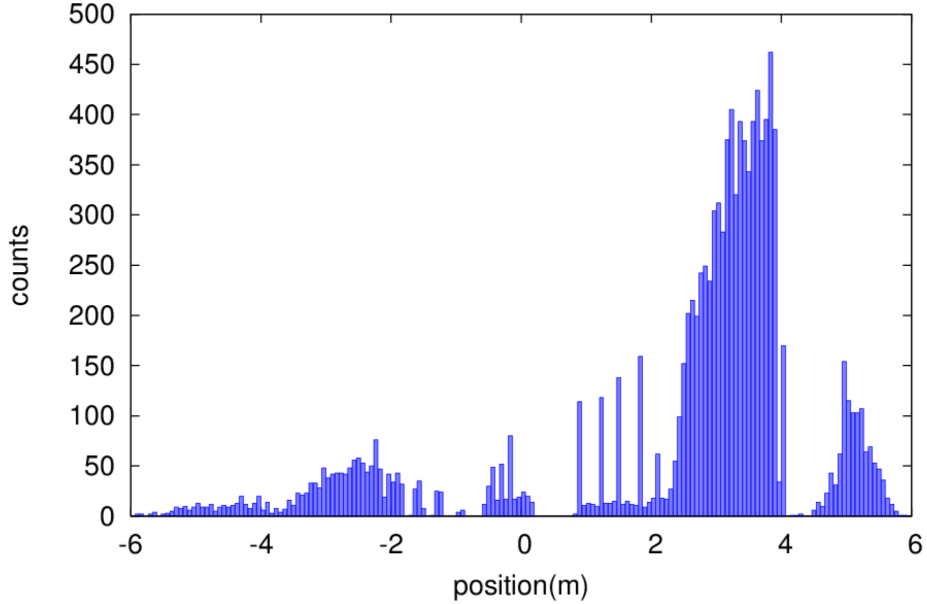
- According to the off-momentum dynamic aperture after optimizing the CEPC lattice, and considering the beam-beam effect and errors, the energy acceptance of CEPC is about 1.5%.
- When the energy acceptance is 1.5%, the beam-gas bremsstrahlung lifetime is about 63.8 hours.
- Generate ~ 100000 particles.

Beam-Gas bremsstrahlung loss particles

Without RBB collimators

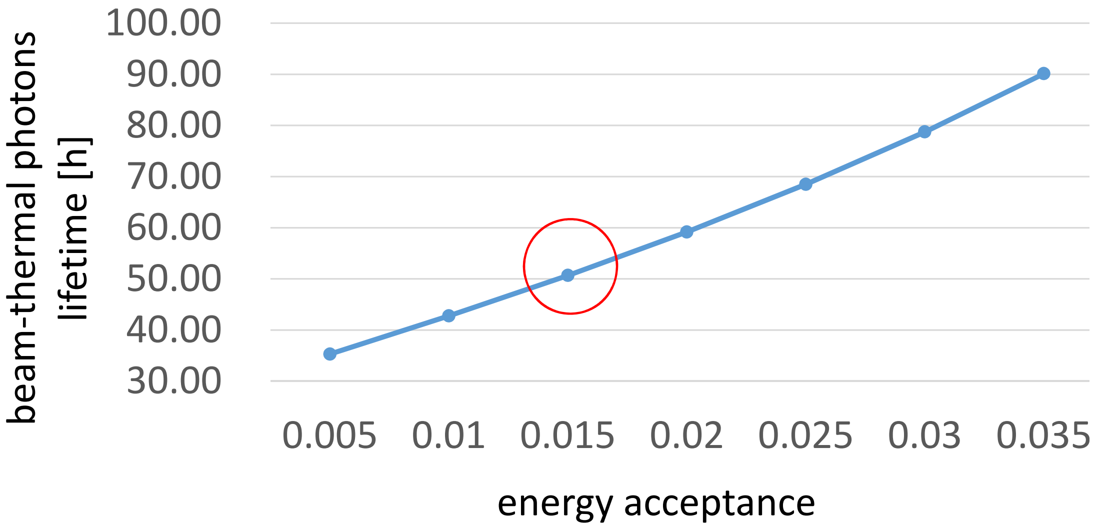


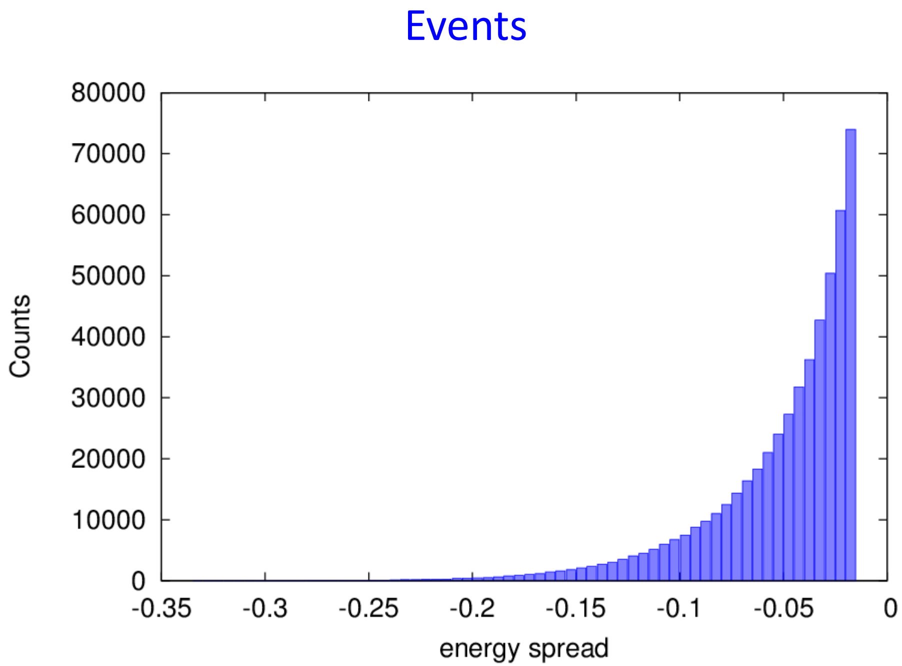
With RBB collimators



- 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

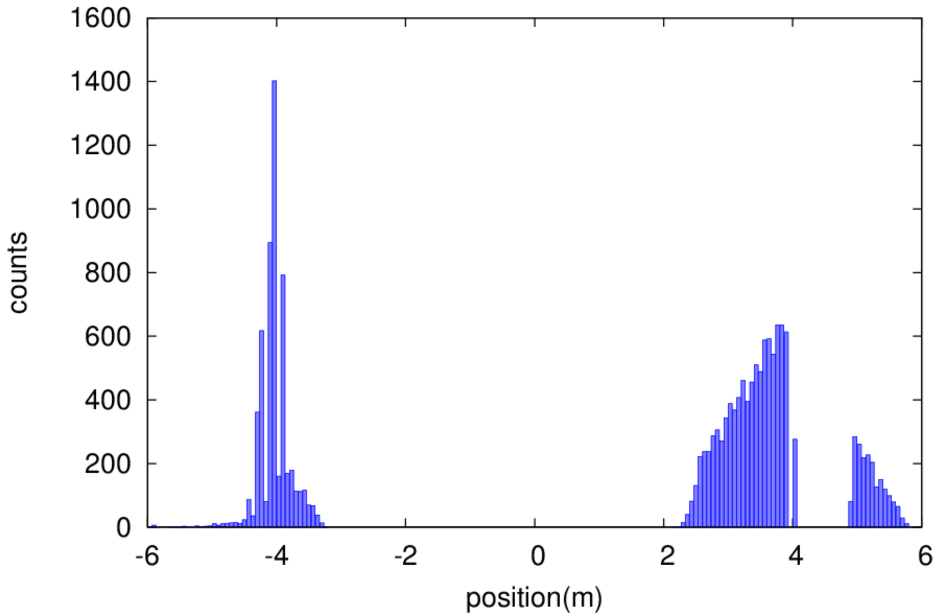




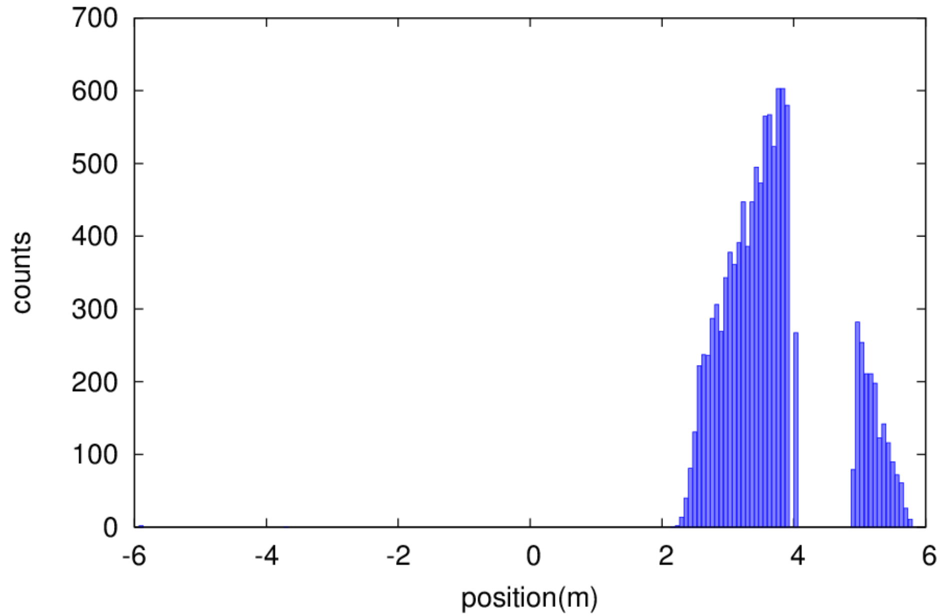
- According to the off-momentum dynamic aperture after optimizing the CEPC lattice, and considering the beam-beam effect and errors, the energy acceptance of CEPC is about 1.5%.
- When the energy acceptance is 1.5%, the beam-thermal photons scattering lifetime is about 50.7 hours.
- Generate ~ 100000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

Beam-Thermal photon scattering loss

Without RBB collimators

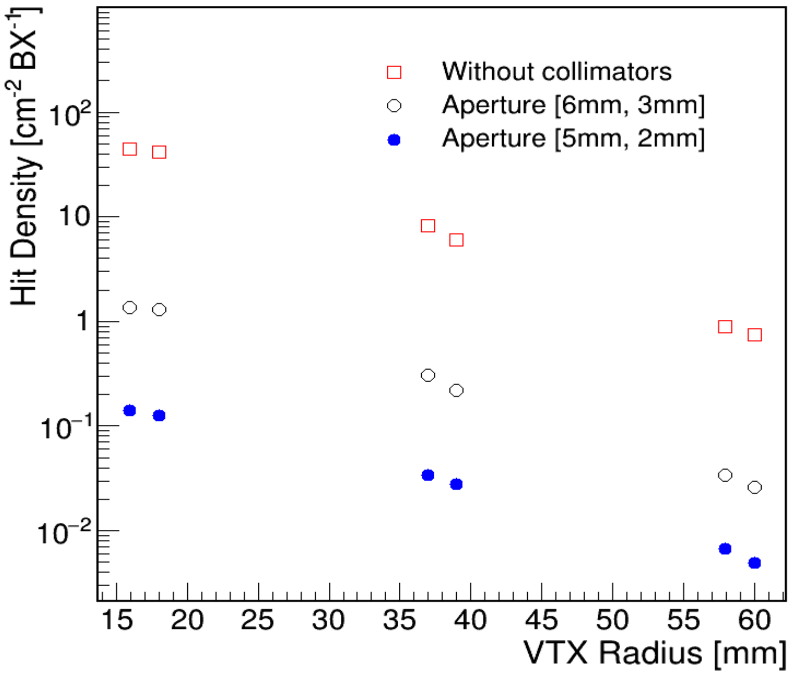


With RBB collimators



- 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.

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

- Although the space of MDI is quite tight, each element can be installed .
- The detector solenoid field effect to the beam can be compensated.
- HOM of IR beam pipe has been simulated and water cooling was considered.
- For both upstream and downstream of IP, the critical energy of synchrotron radiation from the bending magnets is controlled to low level. There is no SR photons within $6\sigma_x$ directly hitting or once-scattering to the detector beam pipe.
- Beam loss background in the upstream of multi-turn tracking seems serious, but with four pairs of horizontal and vertical collimators in ARC(half width 5mm and 2mm), beam loss reduced significantly for Higgs factory.
- The event rate with collimators is acceptable for the CEPC detector for beam loss particles.

Thanks