Machine Detector Interface for CEPC

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for CEPC MDI group

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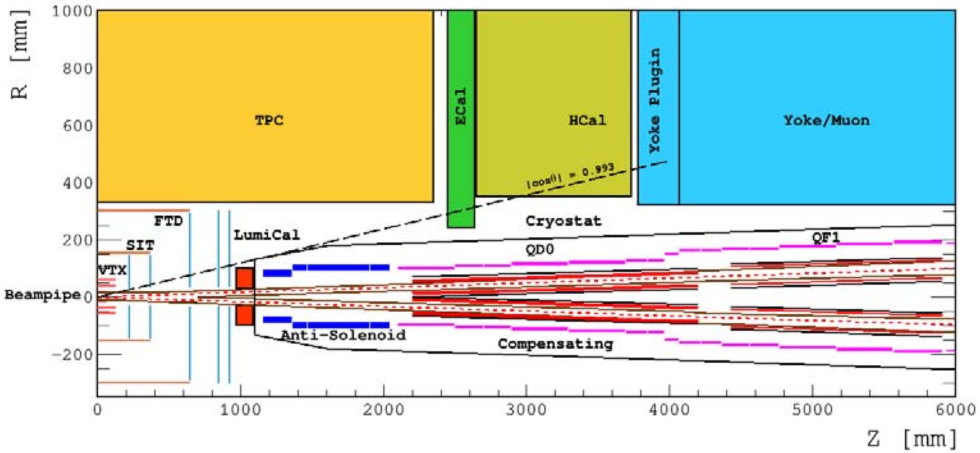
Outline

- MDI layout and IR design
- IR superconducting magnets
- Solenoid compensation
- Synchrotron radiation and mask design
- Beam loss background and collimator design
- Mechanics and assembly
- Summary

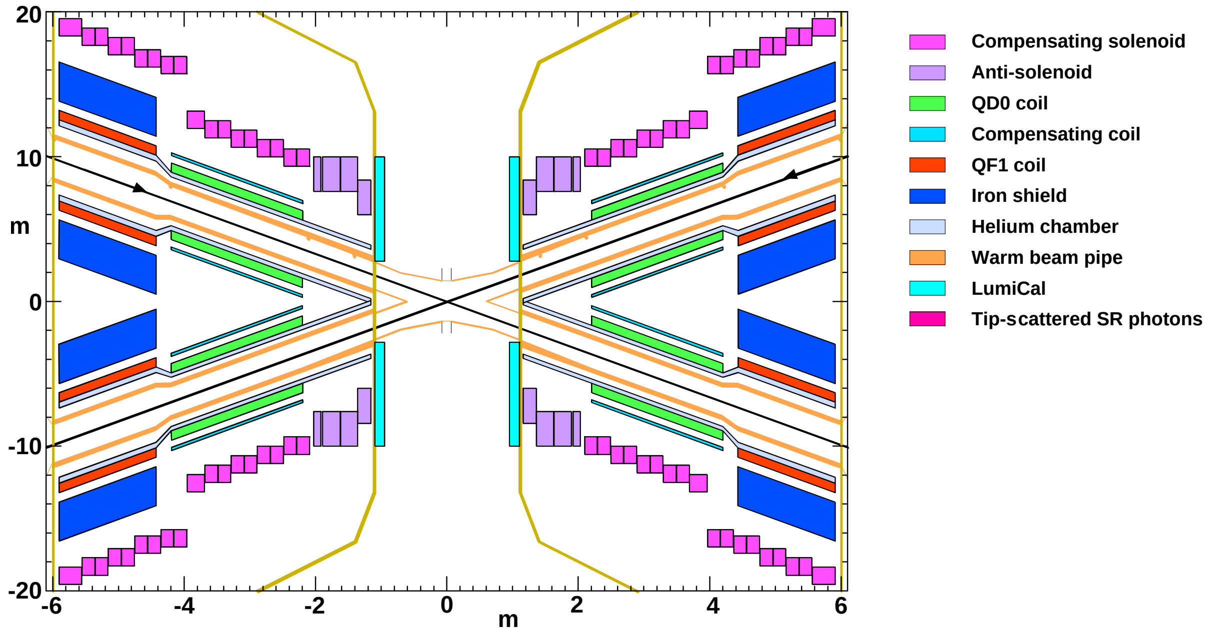
MDI layout and IR design

With Detector solenoid



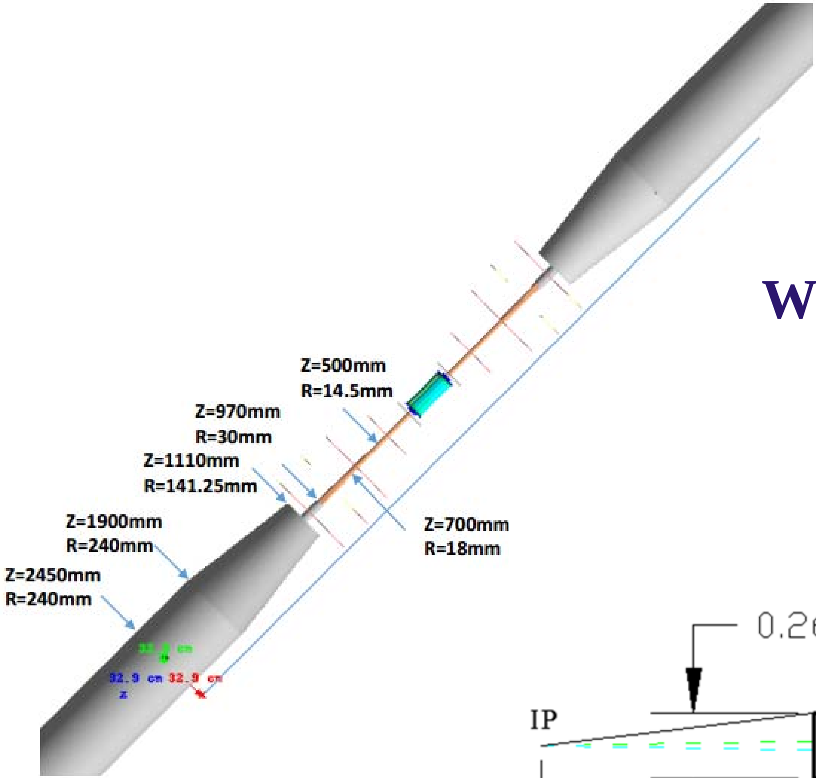
- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993.
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m
- Lumical will be installed in longitudinal 0.95~1.11m, with inner radius 28.5mm and outer radius 100mm.

Without Detector solenoid
~cryostat in detail

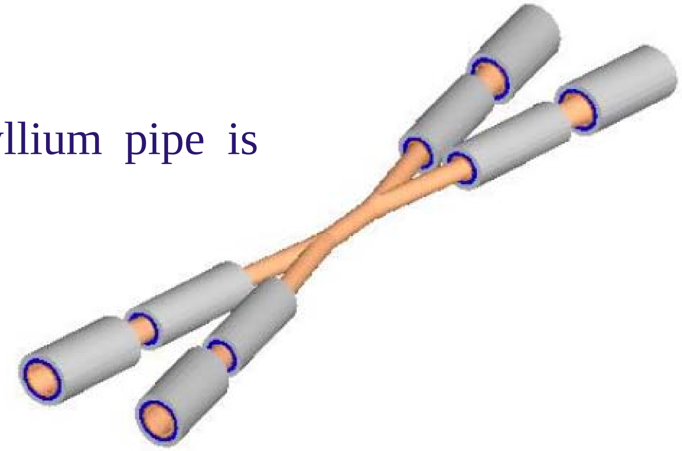


- The Machine Detector Interface (MDI) of CEPC double ring scheme is about ±7m long from the IP
- The CEPC detector superconducting solenoid with 3T magnetic field and the length of 7.6m.

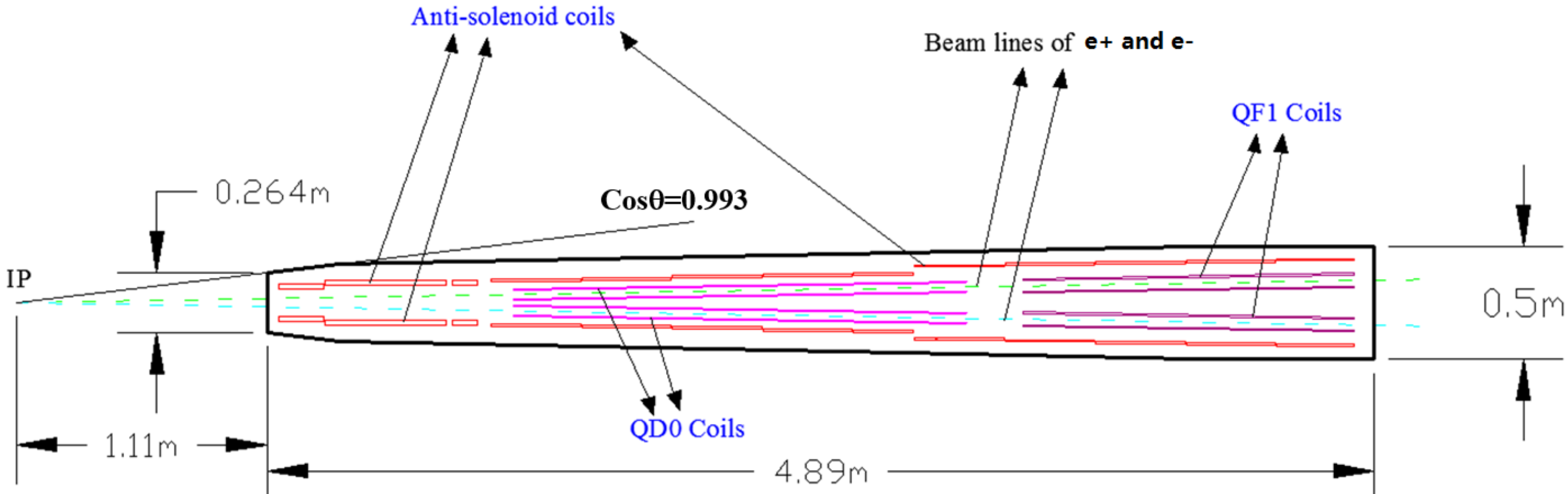
The design of interaction region



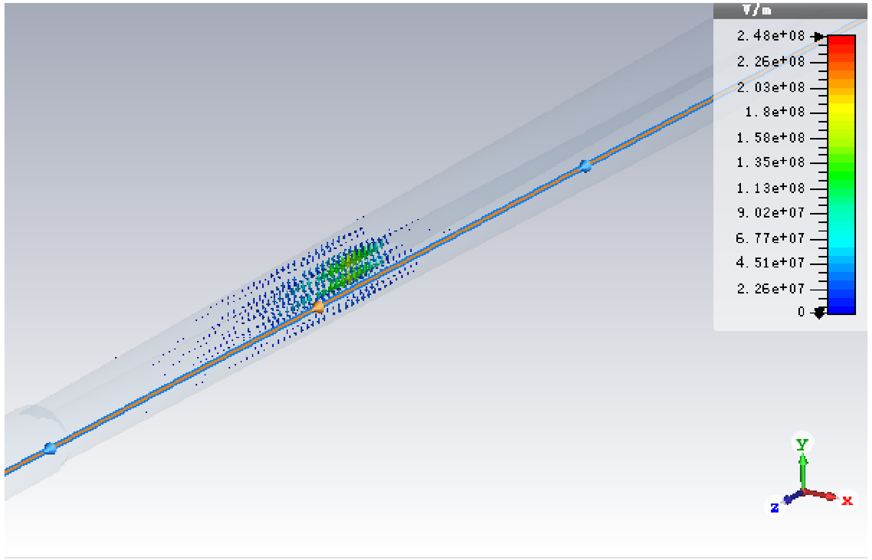
The inner diameter of the beryllium pipe is 28mm with the length of ±7cm.

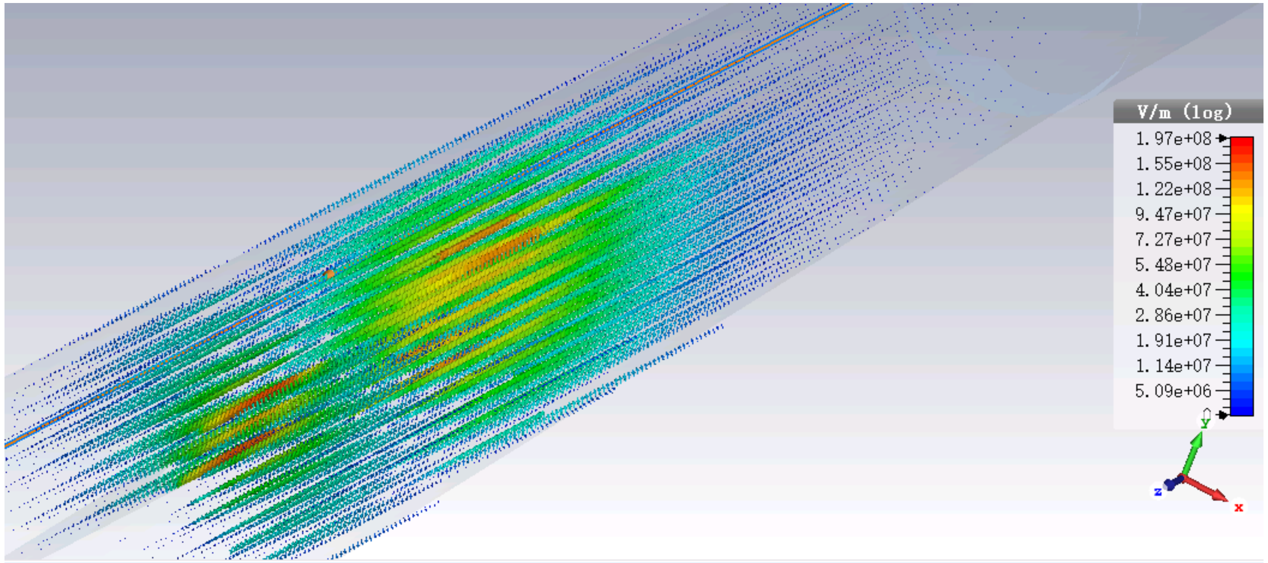


Without tungsten shield.



HOM absorber



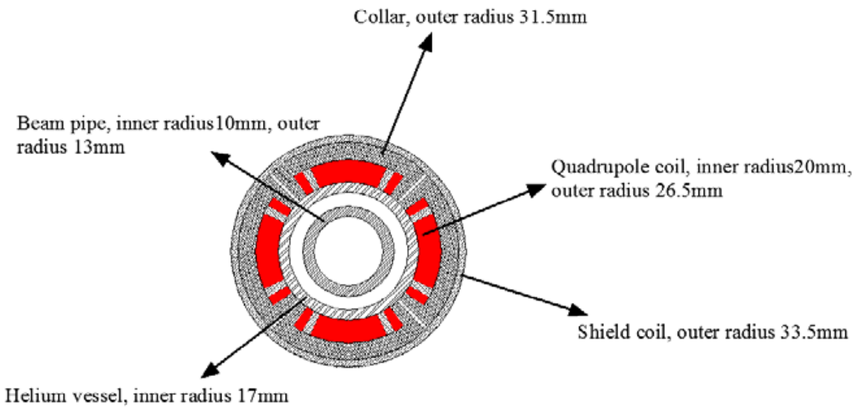


- **TE mode, at crotch point (z~±700mm)**
- **Frenquency 3.2996GHz，Qe=1.42x10^{12}**
- **This mode is trapped mode.**
- **HOM absorber is needed，water cooling system considered.**
- **With the high order mode of this TE mode, eg. 3.715GHz.**
- **The boundary between accelerator and detector is still not clear. The design of HOM absorber can't be confirmed in short period.**

IR Superconducting magnets

Superconducting QD coils

Rutherford NbTi-Cu Cable

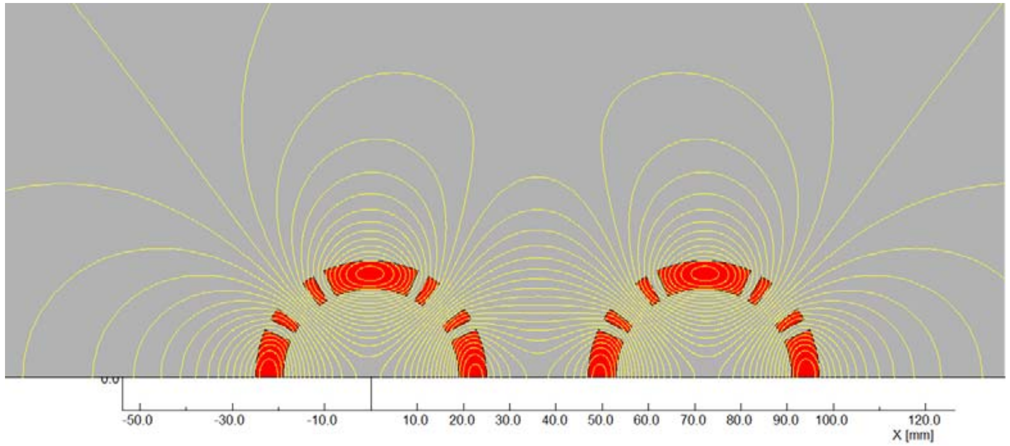


Single aperture of QD0
(Peak field 3.2T)

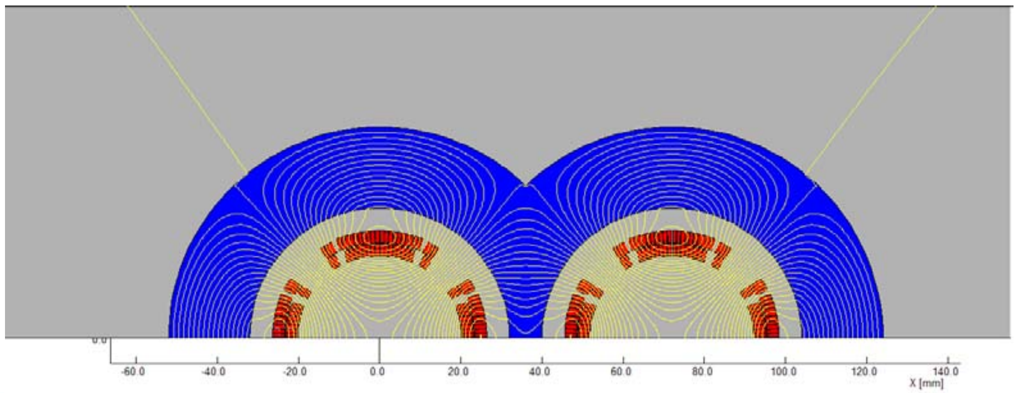
Room-temperature vacuum chamber with a clearance gap of 4 mm

Magnet	Central field gradient (T/m)	Magnetic length (m)	Width of Beam stay clear (mm)	Min. distance between beams centre (mm)
QD0	136	2.0	19.51	72.61

Two options w/o iron yoke.



Iron option for QD0 is investigated.

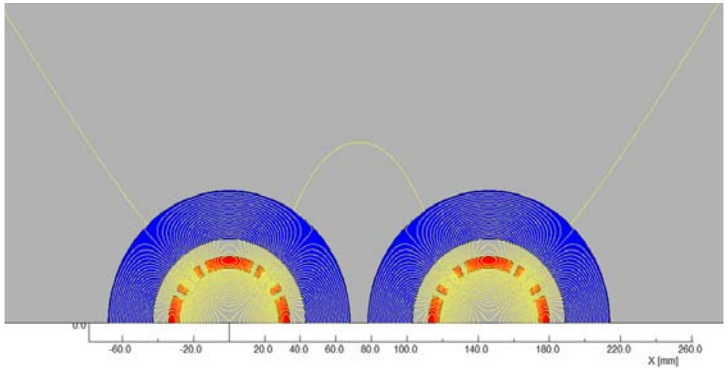


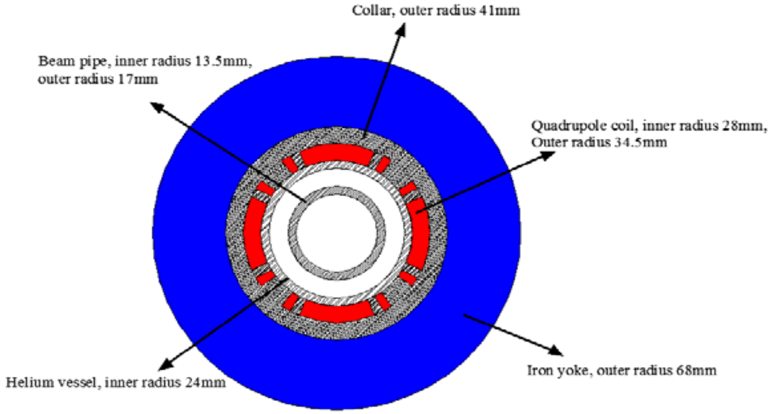
IR Superconducting magnets

Superconducting QF coils

There is iron yoke around the quadrupole coil for QF1. Since the distance between the two apertures is larger enough and there is iron yoke, the field cross talk between two apertures of QF1 can be eliminated.

Rutherford NbTi-Cu Cable





One of QF1 aperture
(Peak field 3.8T)

Room-temperature vacuum chamber with a clearance gap of 7 mm

Magnet	Central field gradient (T/m)	Magnetic length (m)	Width of Beam stay clear (mm)	Min. distance between beams centre (mm)
QF1	110	1.48	27.0	146.20

Integral field harmonics with shield coils （$\times 10^{-4}$）

n	B_n/B_2@R=13.5mm
2	10000
6	1.08
10	-0.34
14	0.002

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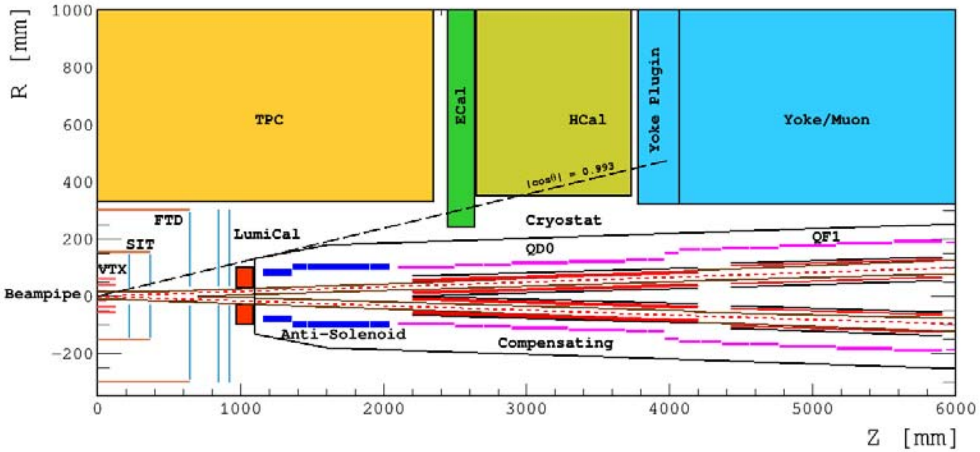
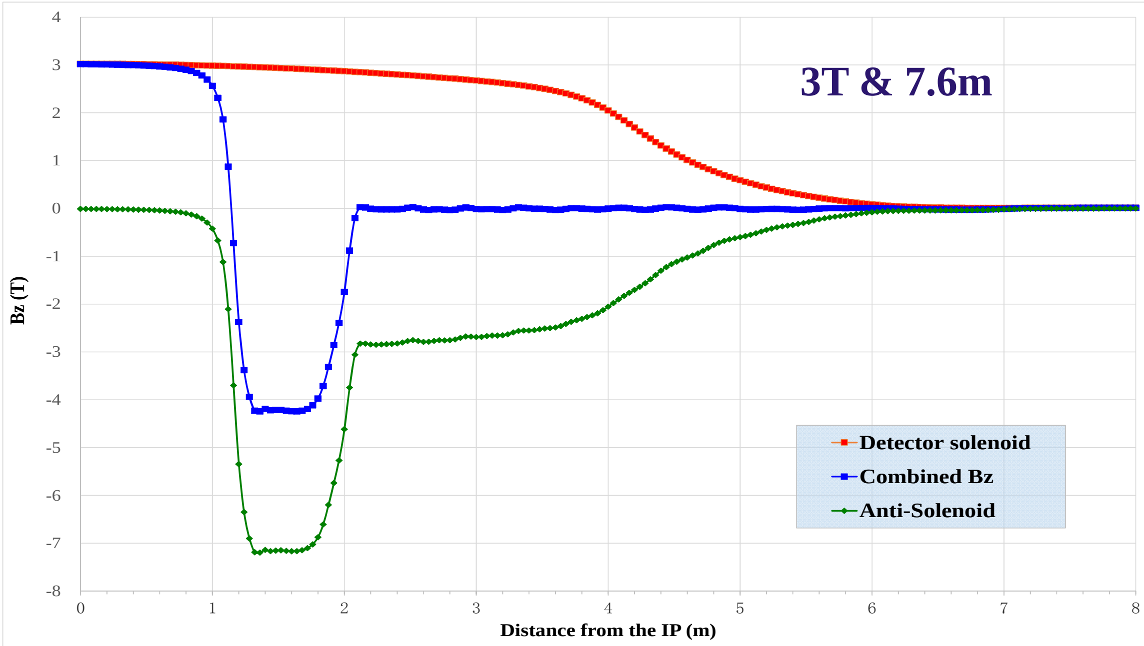
Solenoid compensation



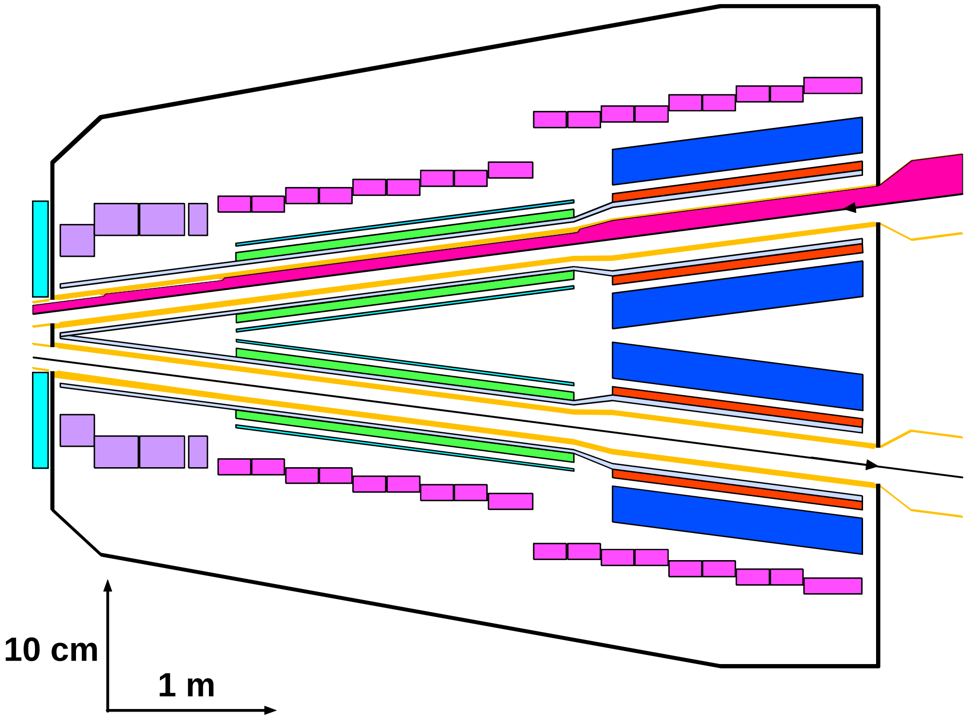


Specification of Anti-Solenoid

Anti-solenoid	Before QD0	Within QD0	After QD0
Central field（T）	7.2	2.8	1.8
Magnetic length（m）	1.1	2.0	1.98
Conductor (NbTi-Cu, mm)	2.5×1.5		
Coil layers	16	8	4/2
Excitation current（kA）	1.0		
Inductance（H）	1.2		
Peak field in coil (T)	7.7	3.0	1.9
Number of sections	4	11	7
Solenoid coil inner diameter (mm)	120		
Solenoid coil outer diameter (mm)	390		
Total Lorentz force F_z (kN)	-75	-13	88
Cryostat diameter (mm)	500		

- **$\int B_z ds$ within 0~2.12m. Bz < 300Gauss away from 2.12m**
- The skew quadrupole coils are designed to make fine tuning of Bz over the QF&QD region instead of the mechanical rotation.

SR from bends of IR

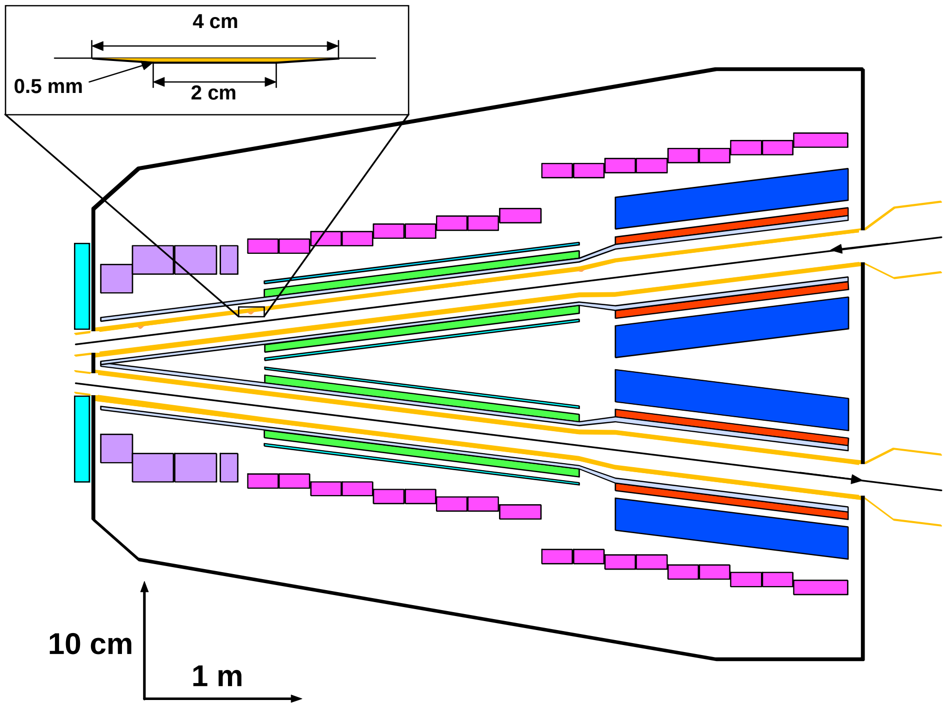


Surface	Power (W)	SR photons > 1 keV
Under QF1	2.51	1.01×10^{9}
Between QF1 and QD0	40.04	1.63×10^{10}
Under QD0	8.08	3.26×10^{9}
In front of QD0	4.45	1.80×10^{9}

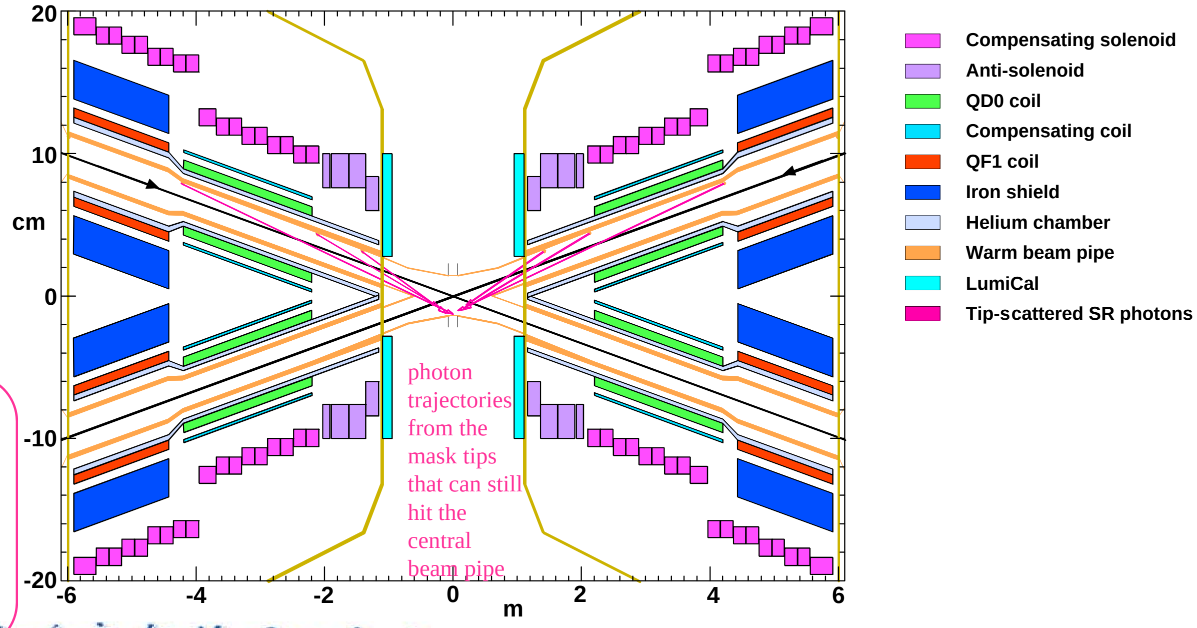
- ✓ A significant fraction of these incident photons will forward scatter from the beam pipe surface and hit the central Be beam pipe (a cylinder located ±7 cm around the IP with a radius of 14 mm).
- ✓ Masks are needed.

- ✓ IP upstream: **Ec < 120 keV within 400m. Last bend**(66m)**Ec = 45 keV**
- ✓ IP downstream: **Ec < 300 keV within 250m**, first bend **Ec = 97 keV**

Mask design of IR

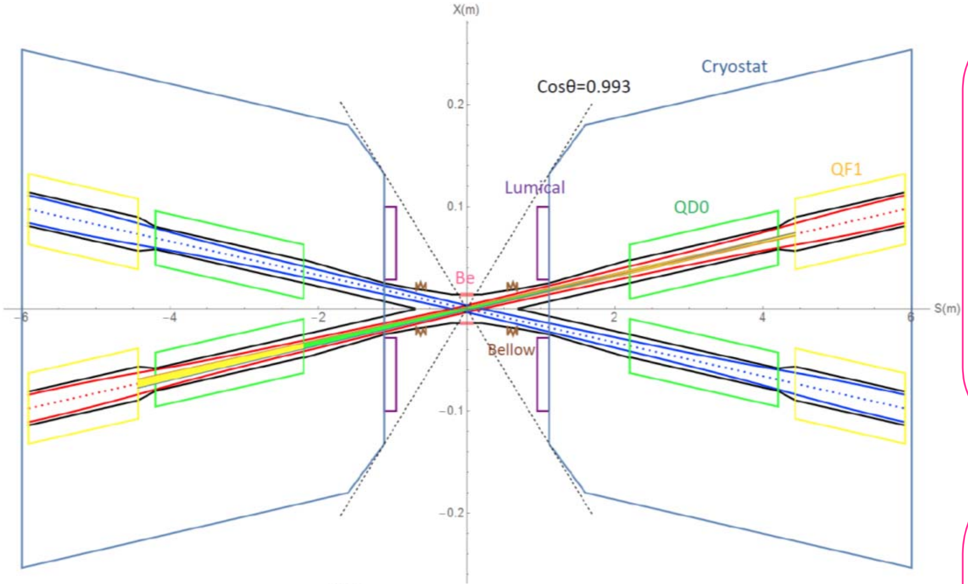


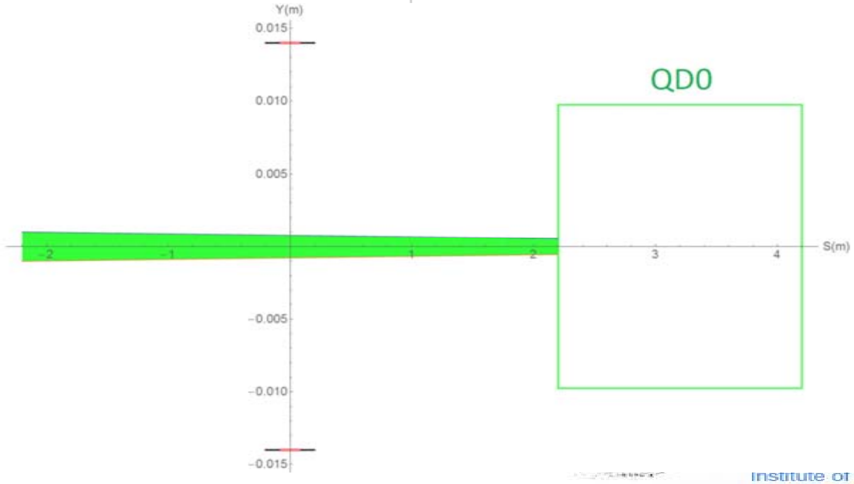
3 mask tips are added to shadow the beam pipe wall reduces the number of photons that hit the Be beam pipe from 2×10^4 to about 200 (100 times lower).



The number of scattered photons that can hit the central beam pipe is greatly reduced to only those photons which forward scatter through the mask tips. The optimization of the mask tips (position, geometry and material) is presently under study.

SR from Final doublet quadrupoles

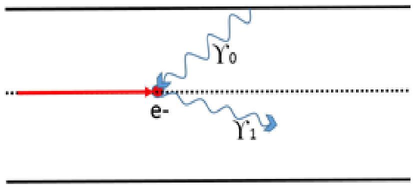




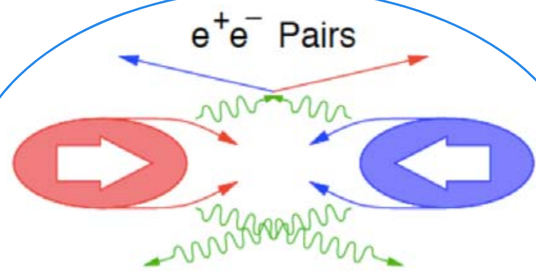
- ✓ The total SR power generated by the QD magnet is 639W in horizontal and 166W in vertical. The critical energy of photons are about 1.3 MeV and 397keV in horizontal and vertical.
- ✓ The total SR power generated by the QF1 magnet is 1567W in horizontal and 42W in vertical. The critical energies of photons are about 1.6MeV and 225keV in horizontal and vertical.

- ✓ No SR photons within 10 σ_x directly hitting or once-scattering to the detector beam pipe.
- ✓ Collimators for the beam loss will cut beam to 13σ_x. SR photons generated from 10σ_x to 13σ_x will hit downstream of the IR beam pipe, and the once-scattering photons will not go into the detector beam pipe but goes to even far away from the IP region.
- ✓ SR photons from final doublet quadrupoles will not damage the detector components and cause background to experiments.

Beam loss Backgrounds at CEPC



Beam-Thermal photon scattering



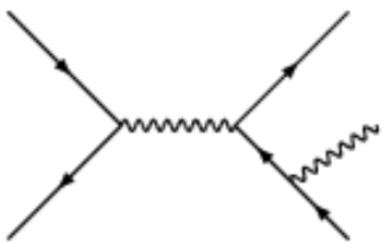
Beamstrahlung

IP1

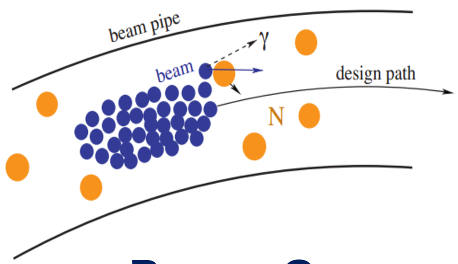
242 bunches
Revolution frequency: **2997**Hz
1.5×10^{11} particles/Bunch
L: $3 \times 10^{34} cm^{-2} s^{-1}$

IP3

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



Radiative Bhabha scattering

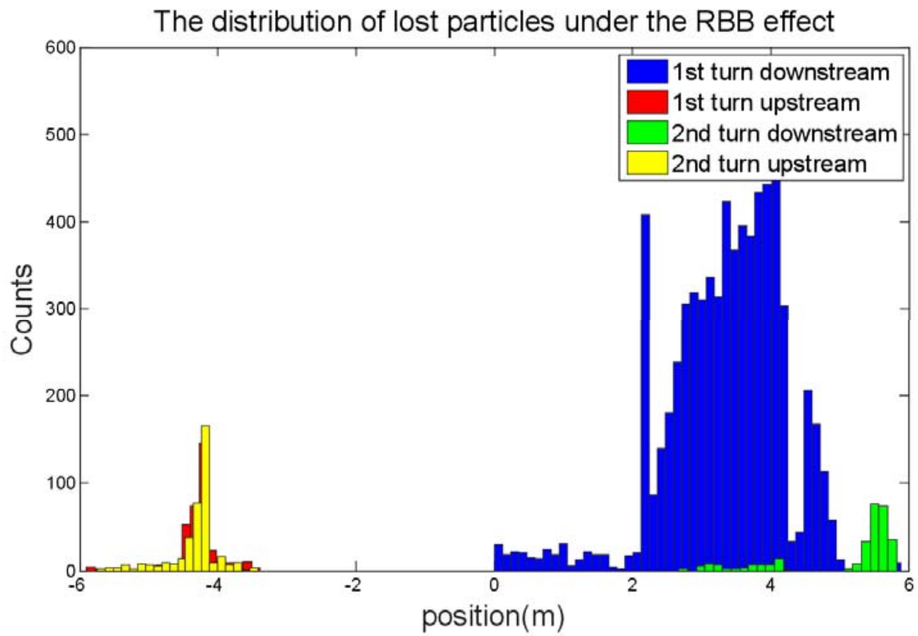


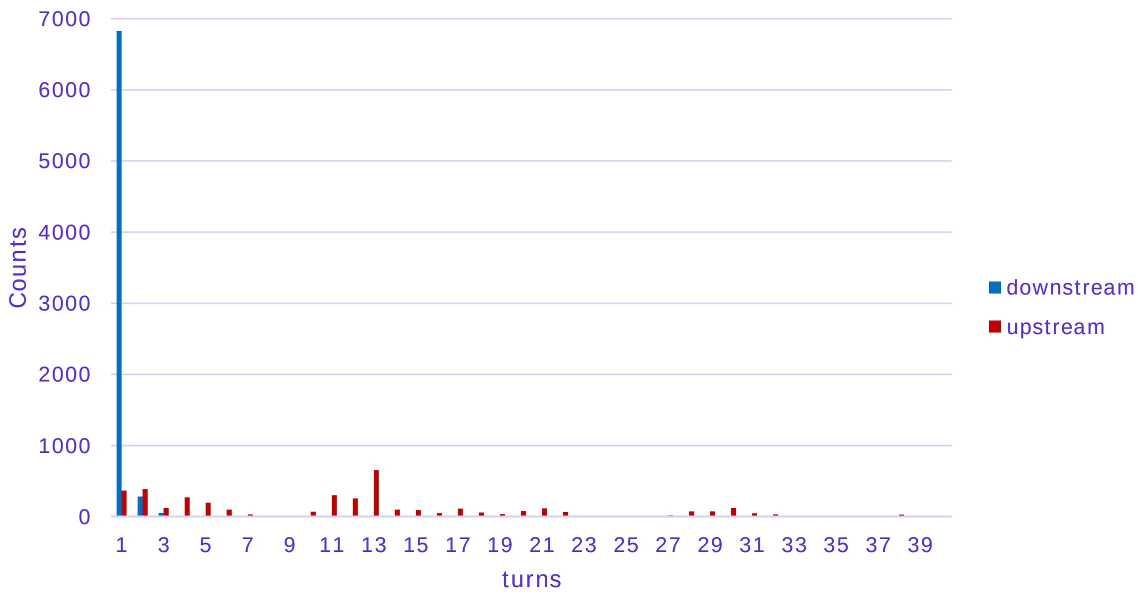
Beam-Gas Scattering

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	74 min	
Beamstrahlung	80 min	

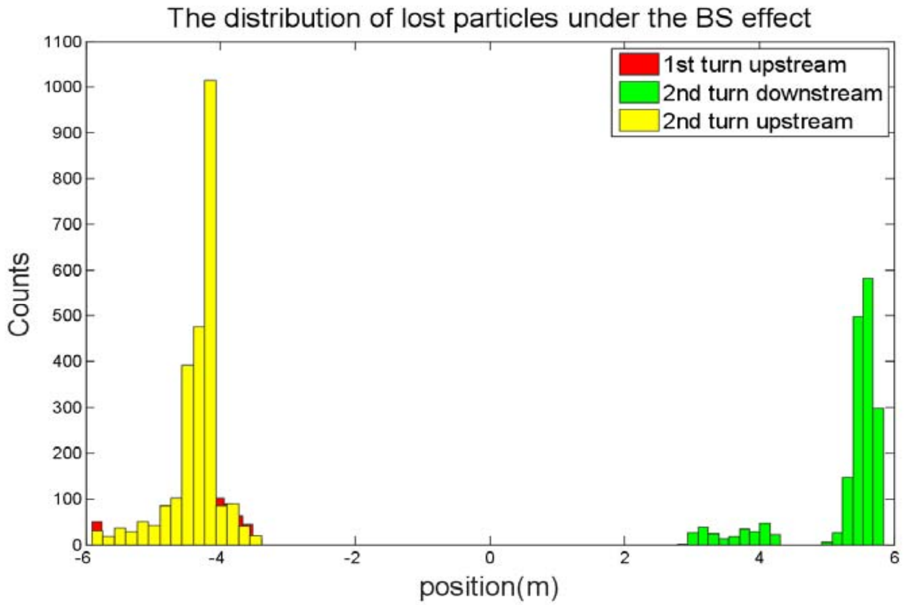
Loss particles due to RBB

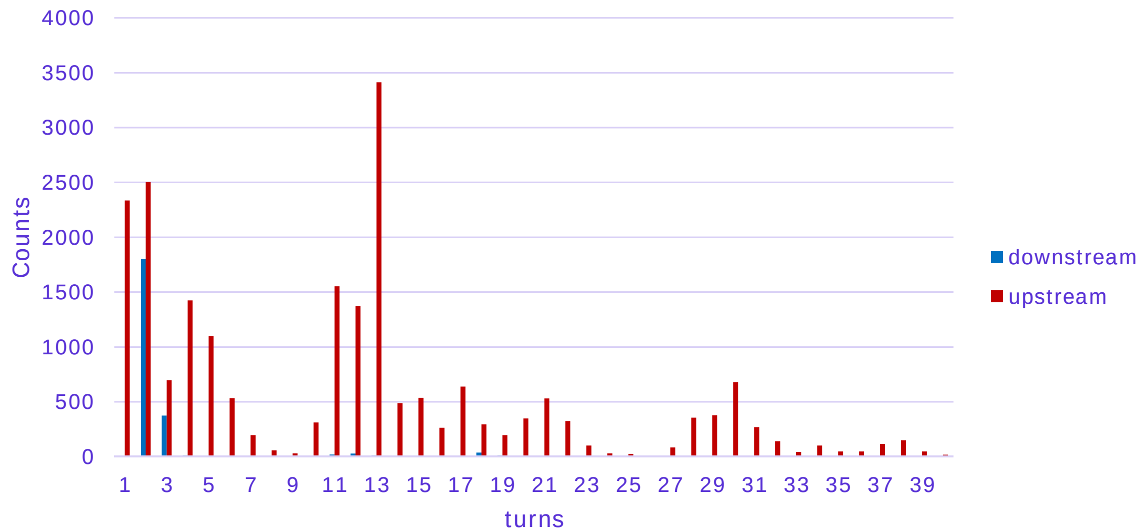




- Most the events lost in the detector immediately. A few particles with high energy will lost near the IP after one revolution for a small energy loss.
- Although pretty large fraction of events lost in the downstream region, the radiation damage for detector component is tolerable.
- Compared to the 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.

Loss particles due to BS





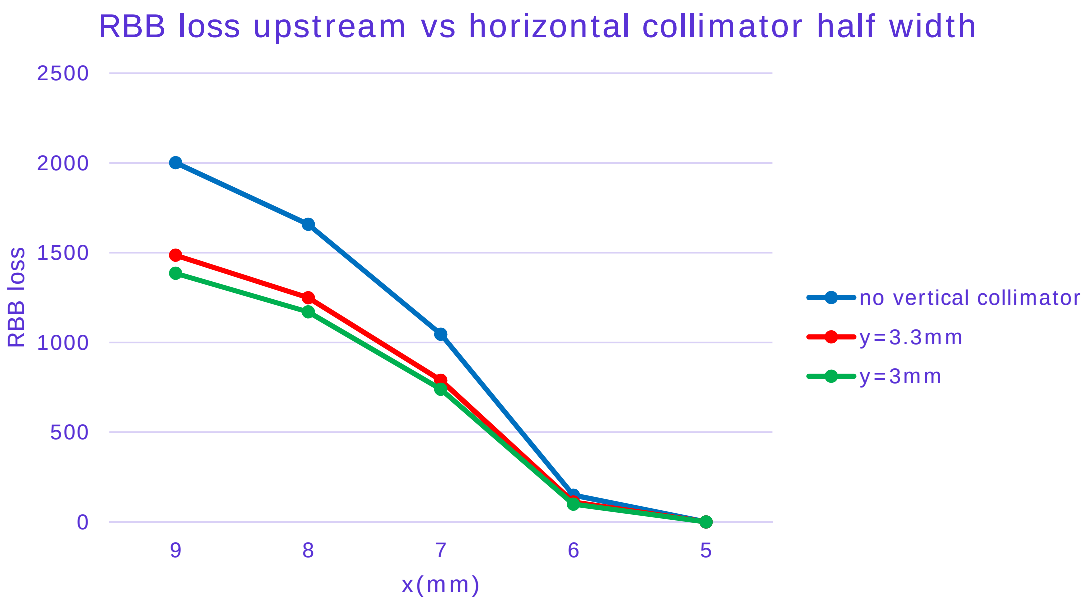
- Energy spread distribution close to the energy acceptance, the beam loss particles not appeared in the downstream of first turn.
- Compared to the one turn's tracking, more particles get lost in the upstream region of the IR.
- The events lost in the upstream region are more dangerous for they are likely permeate into the detector components, even with the small flying angle respect to the longitudinal direction considered.
- Collimators are needed.

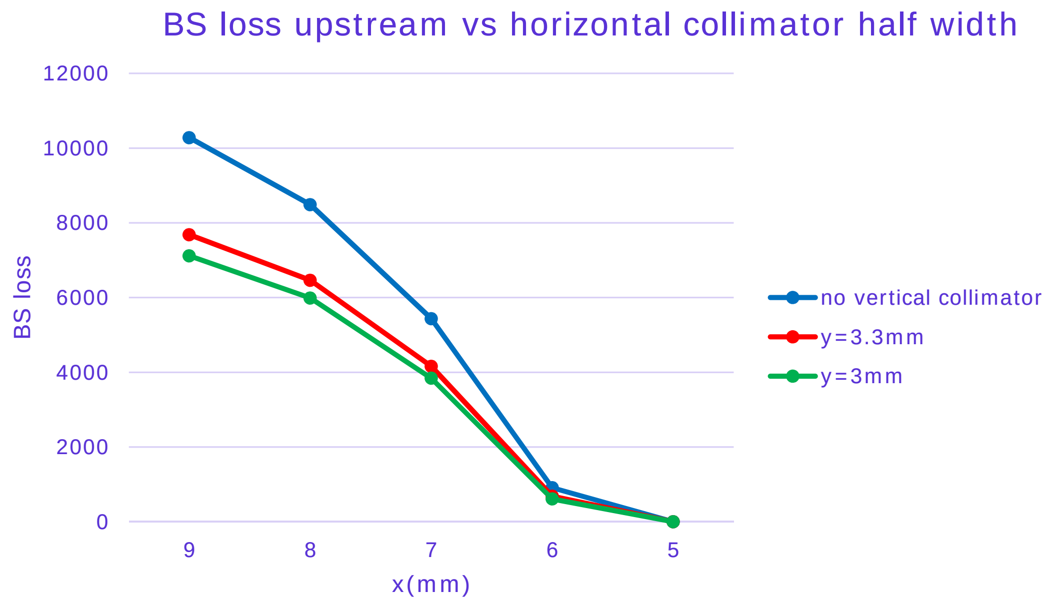
Collimator design in ARC for Higgs

- 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 / m m
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 and BS 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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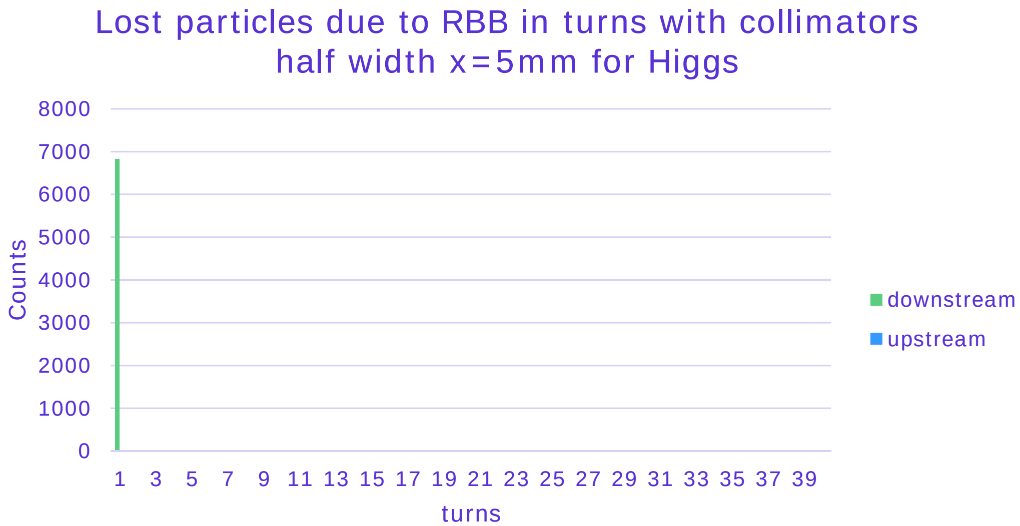
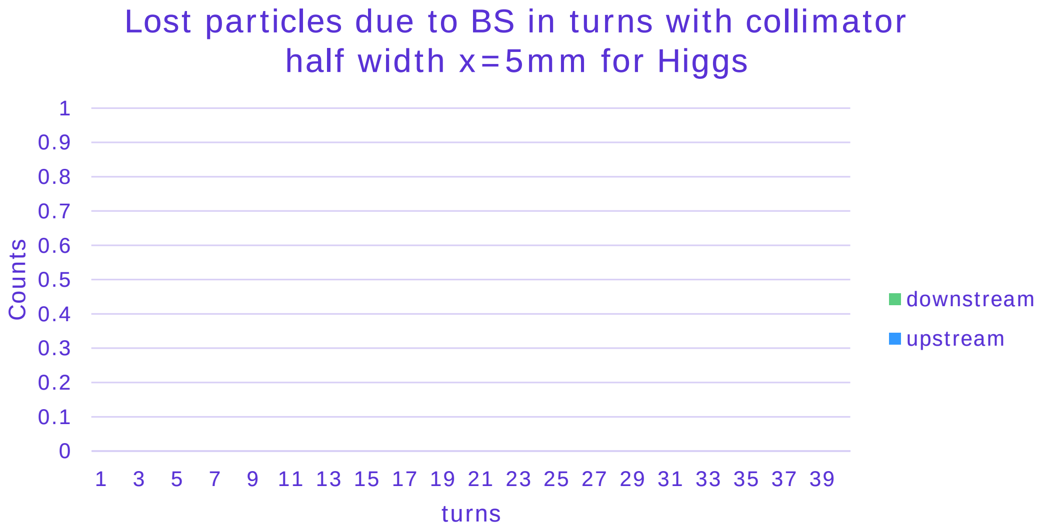
RBB and BS loss with collimators for Higgs

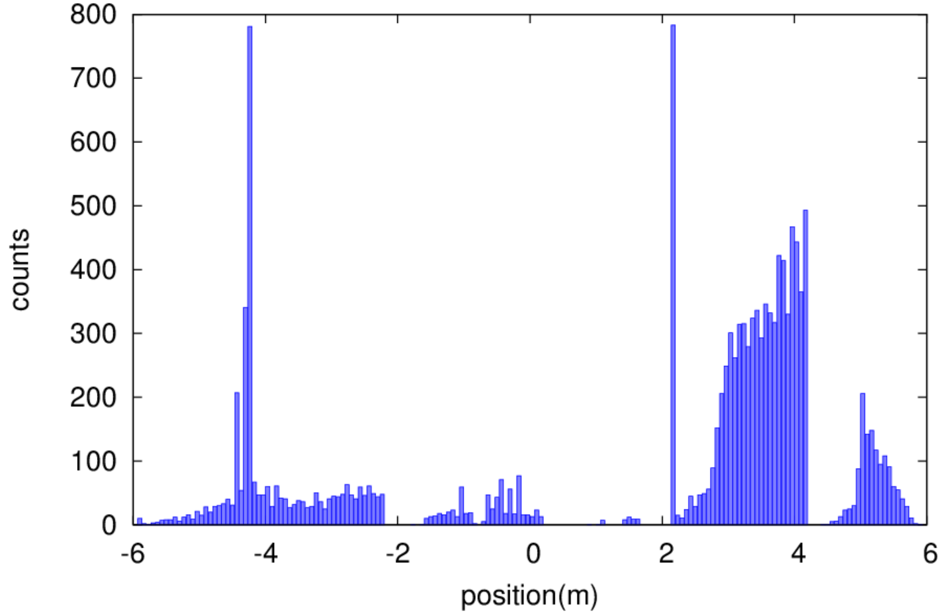




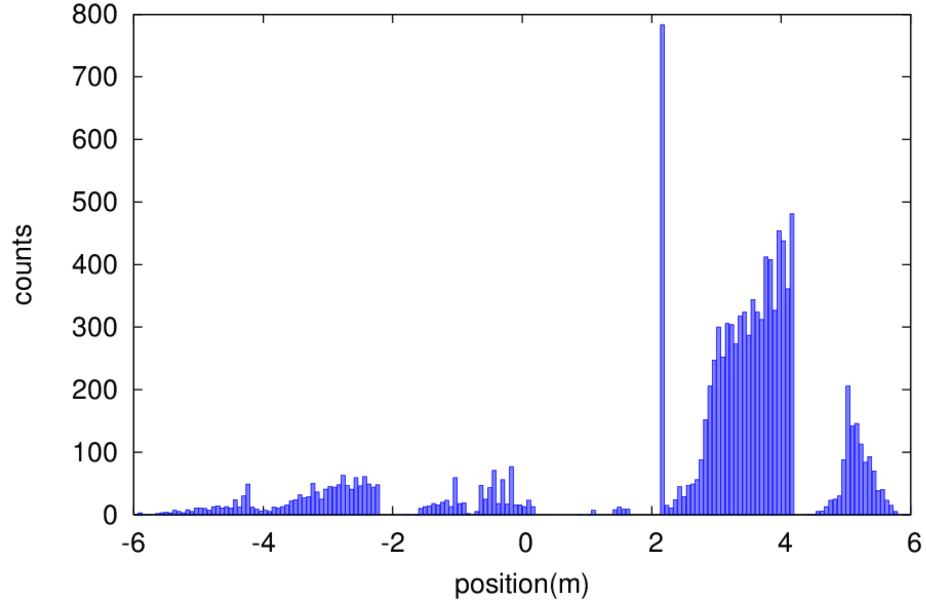
- horizontal collimator half width 5mm(13σ_x)
- The collimators will not have effect on the beam quantum lifetime.
- The lost particles has been reduced to a very low level with the system of collimators, especially in the upstream of the IP.
- Although the beam loss in the downstream of the IP is still 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 loss particles

Without collimators



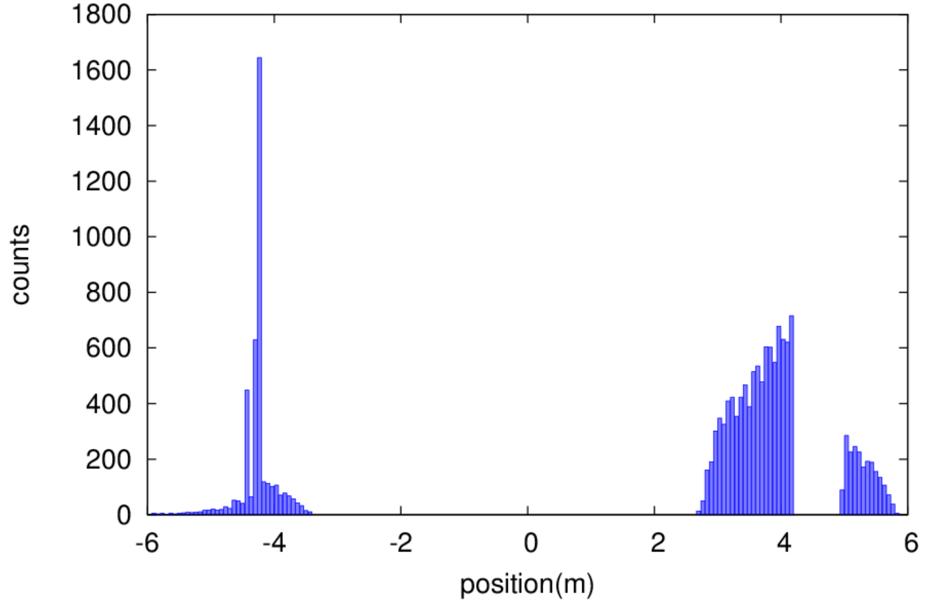
With collimators



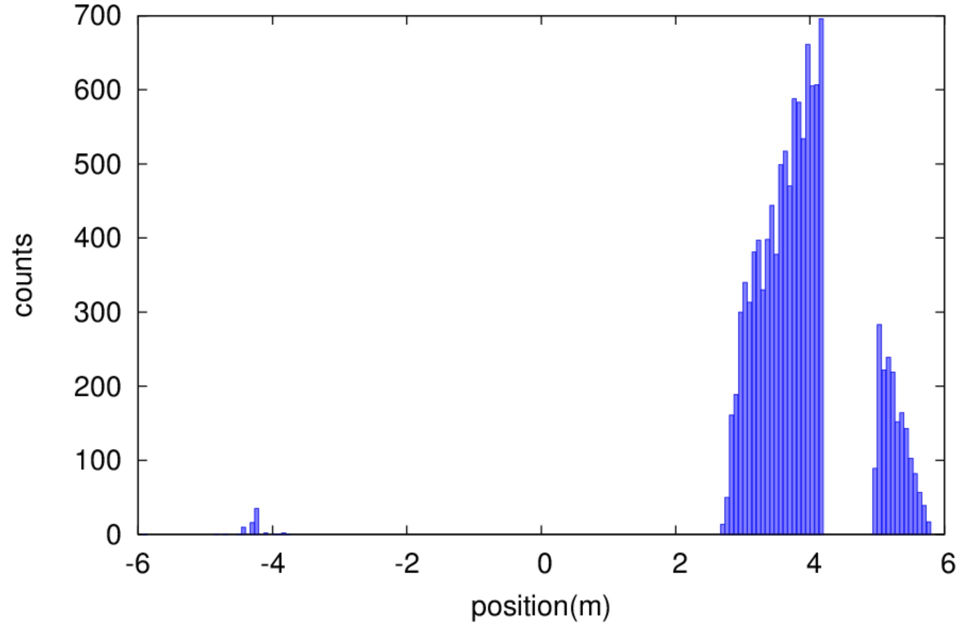
- The lost particles has been reduced to a very low level with RBB collimators, especially in the upstream of the IP, can be accepted by the detector.
- Although the beam loss in the downstream of the IP is still remained, the radiation damage and the detector background are not serious, since the direction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

Beam-Thermal photon scattering 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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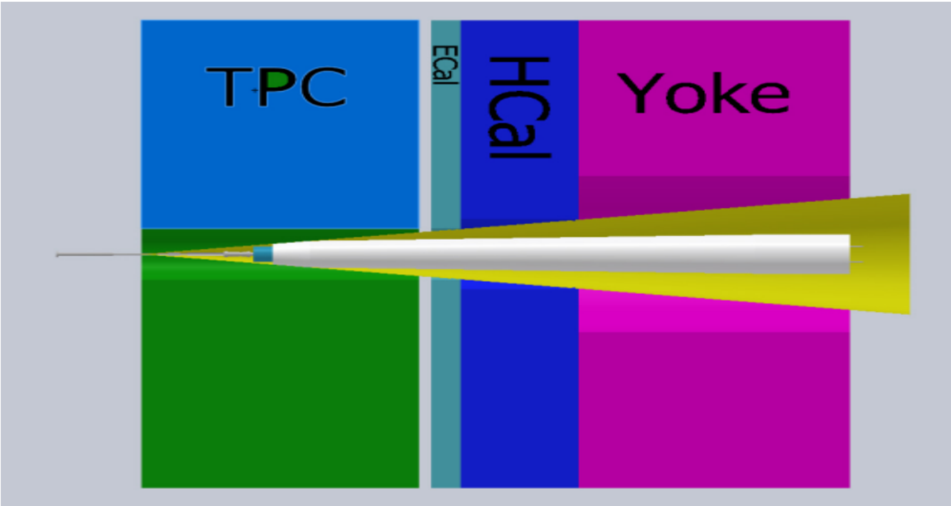
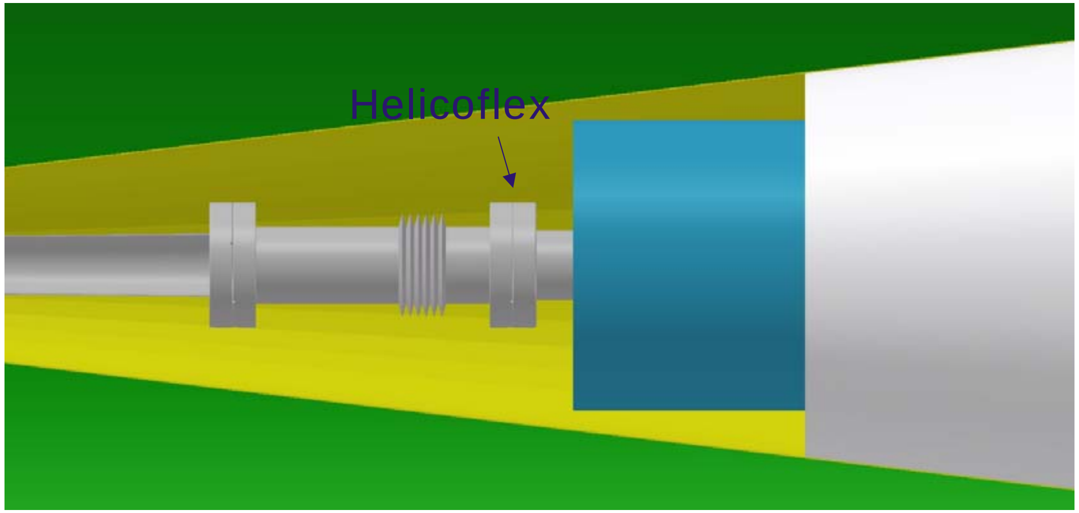
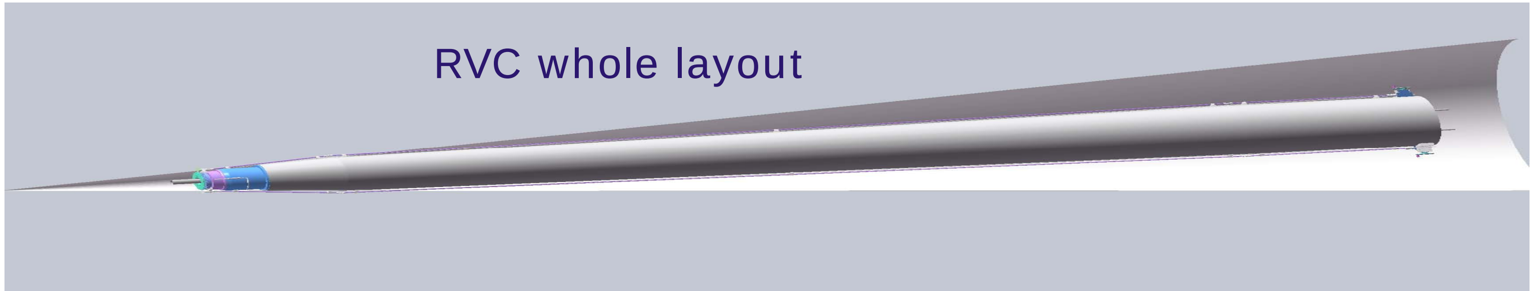
IR mechanics assembly





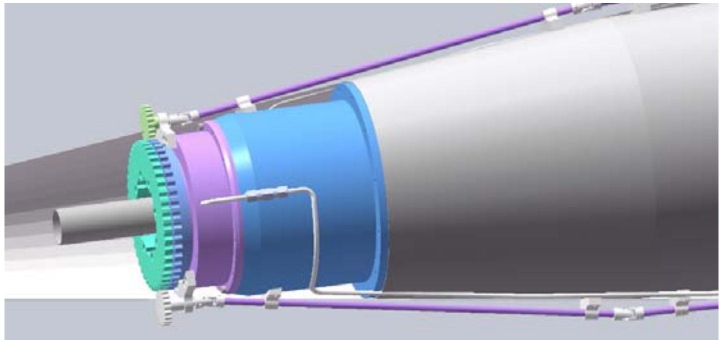


- IR mechanics assembly typical point is remote vacuum connection.
- The sealing point is 6m away from the operation point.
- Ultrahigh vacuum sealing, Helicoflex.

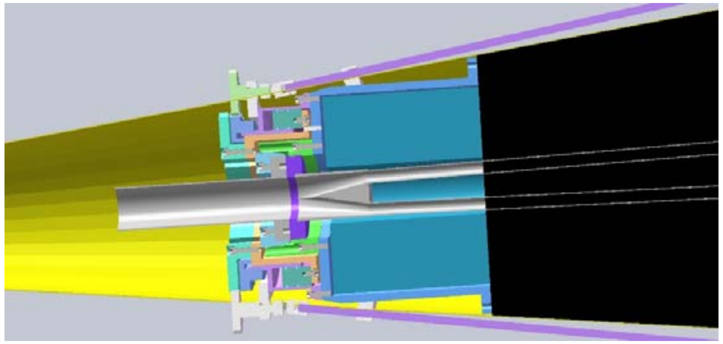
IR Mechanics Assembly

- No easy solution to install all the critical components in the IR with high precision; inspired by the Remote Vacuum Connection (RVC) developed by SuperKEKB
- We are studying the special installation tools for the remote connection of bellows.

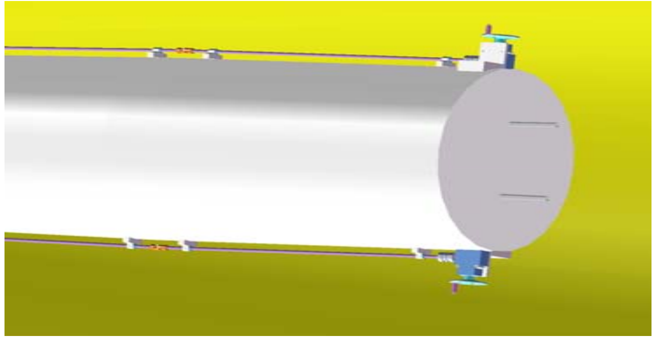
RVC head and drive gear



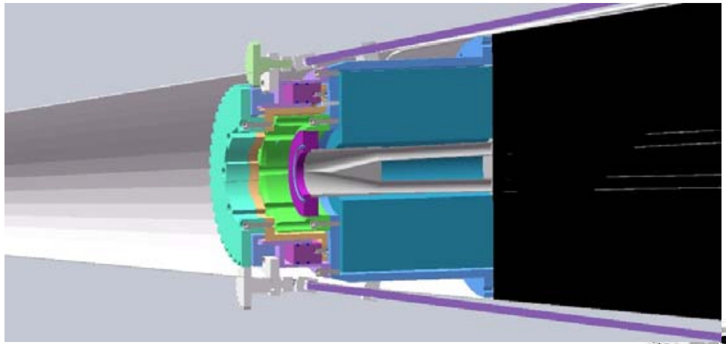
cutaway view of RVC head



RVC tail/handwheel structure



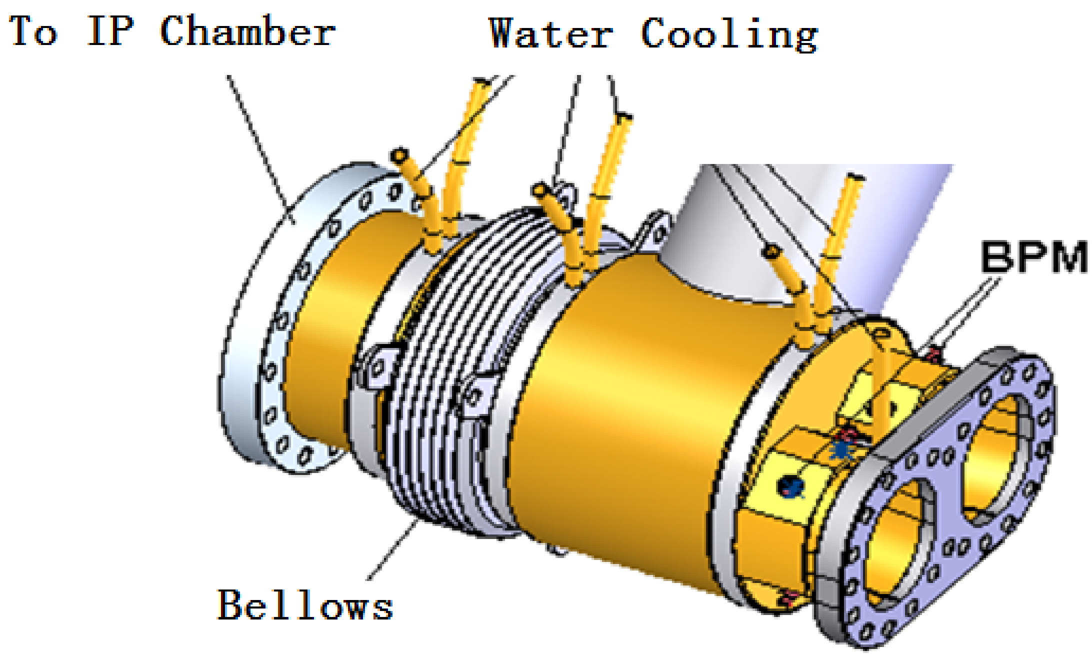
Cutaway view of moving part

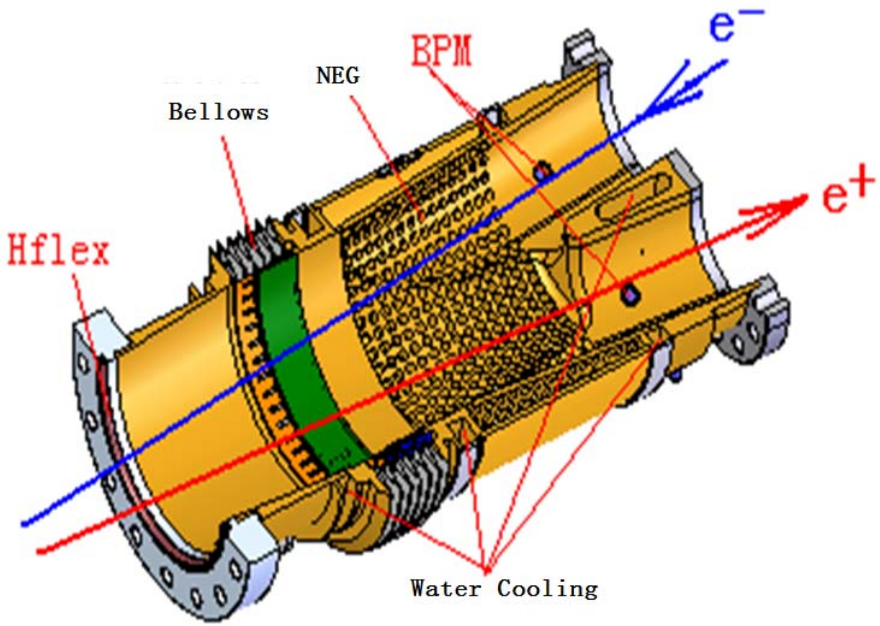


RVC is under development

Assembly nearby the IP

Crotch region





Helicoflex

Summary

- The finalization of the beam parameters and the specification of special magnets have been finished. The parameters are all reasonable.
- The detector solenoid field effect to the beam can be compensated.
- HOM of IR beam pipe has been simulated and water cooling was considered.
- Beam lifetime of CEPC double ring scheme is evaluated.
- The most importance beam loss background is radiative Bhabha scattering and beamstrahlung for the Higgs factory.
- Collimators are designed in the ARC which is about 2km far from the IP to avoid other backgrounds generation. Beam loss have disappeared in the upstream of IP for both Higgs and Z factory.
- Preliminary procedures for the installation of IP elements are studying. The boundary between detector and accelerator is still not clear. Very long time is needed to confirm the final scheme.
- Towards TDR, many of the MDI components are under development.

Reference

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Thanks