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ias
HKUST JOCKEY CLUB INSTITUTE FOR ADVANCED STUDY

CEPC MDI Accelerator Issues

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for CEPC MDI group

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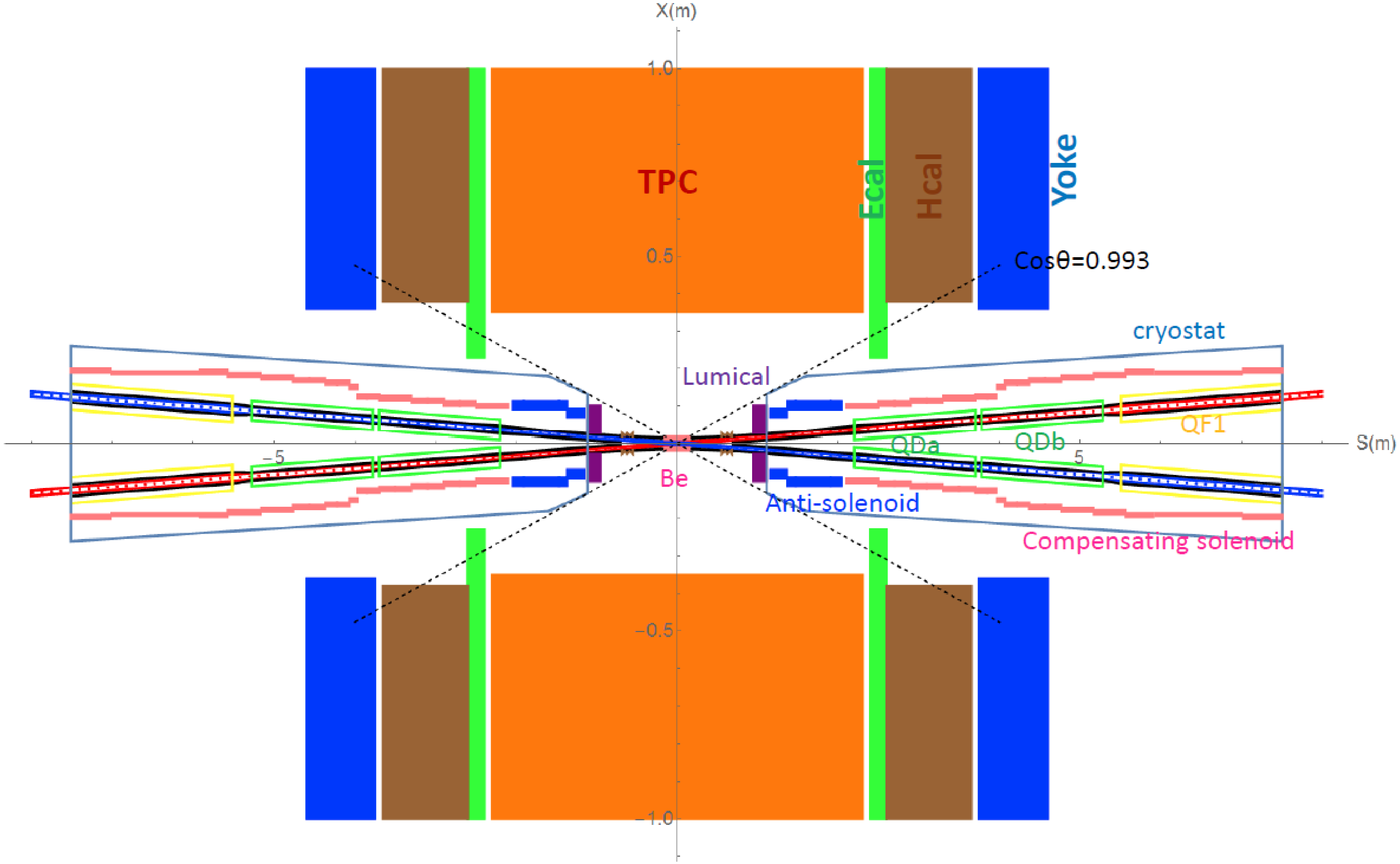
Outline

- MDI layout and IR design
- IR SC magnets physics design parameters
- Solenoid compensation
- Synchrotron radiation
- Beam loss in IR
- Collimator design
- HOM absorber
- IP BPM
- Summary

MDI layout and IR design



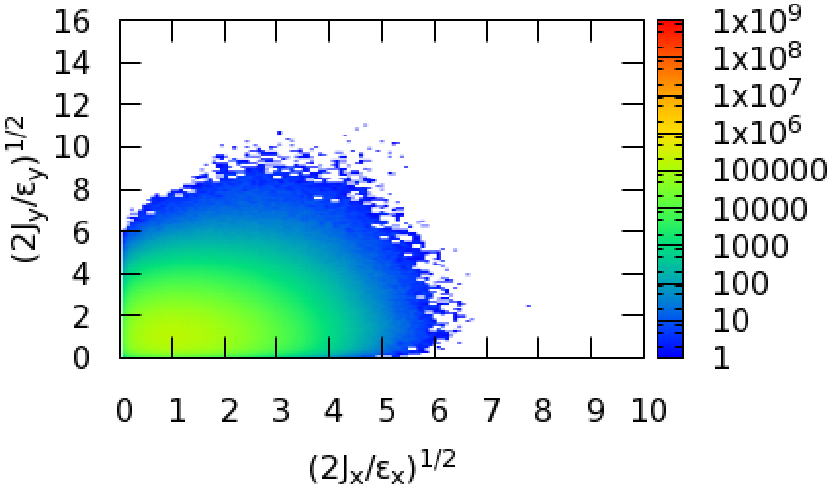
- The Machine Detector Interface (MDI) of CEPC double ring scheme is about ±7m long from the IP.
- The CEPC detector superconducting solenoid with 3T magnetic field and the length of 7.6m.
- The accelerator components inside the detector without shielding are within a conical space with an opening angle 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.

MDI parameters

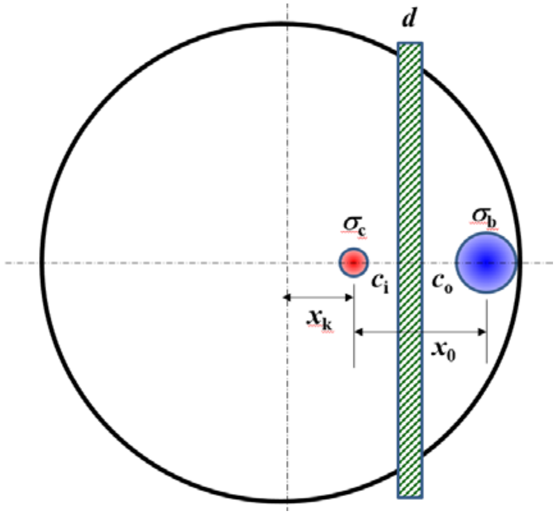
	range	Peak filed in coil	Central filed gradient	Bending angle	length	Beam stay clear region	Minimal distance between two aperture	Inner diameter	Outer diameter	Critical energy (Horizontal)	Critical energy (Vertical)	SR power (Horizontal)	SR power (Vertical)
L*	0~2.2m				2.2m								
Crossing angle	33mrad												
MDI length	±7m												
Detector requirement of accelerator components in opening angle	13.6°												
QDa/QDb		2.4T	77.5T/m		1.5m	19.2/22.0mm	72.61/124.75mm	48mm	59mm	458.7/657.9 keV	271.6/361.5keV	80.9/242.3 W	40.3/65.5W
QF1			63.4T/m		2m	30.9mm	181.85mm	56mm	69mm	428.3keV	613.5keV	245.9W	187.5W
Lumical	0.95~1.11m				0.16m			57mm	200mm				
Anti-solenoid before QD0		7.26T			1.1m			120mm	390mm				
Anti-solenoid QD0		2.8T			2m			120mm	390mm				
Anti-solenoid QF1		1.8T			1.48m			120mm	390mm				
Beryllium pipe					±118mm			28mm					
Last B upstream	83.69~198.7m			0.76mrad	115.01m					25.3keV			
First B downstream	57.04~132.09 m			0.72mrad	75.05m					36.6keV			
Beampipe within QDa/QDb					1.5m							0.75/0.9W	
Beampipe within QF1					2m							1.78W	
Beampipe between QD0/QF1					0.23m							19.6W	

The definition of beam stay clear

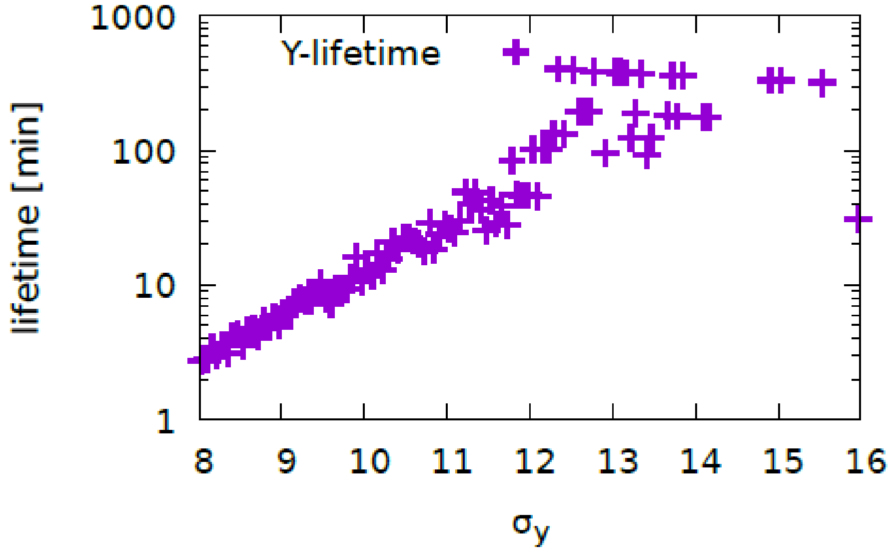
- To satisfy the requirement of injection: **BSC > 13 σ_x**
- To satisfy the requirement of beam lifetime after collision **BSC > 12σ_y**



Beam tail distribution
with full crab-waist



BSC>13 σ_x



BSC>12 σ_y

BSC_x =±(18σ_x +3mm), BSC_y =±(22σ_y +3mm), While coupling=1%

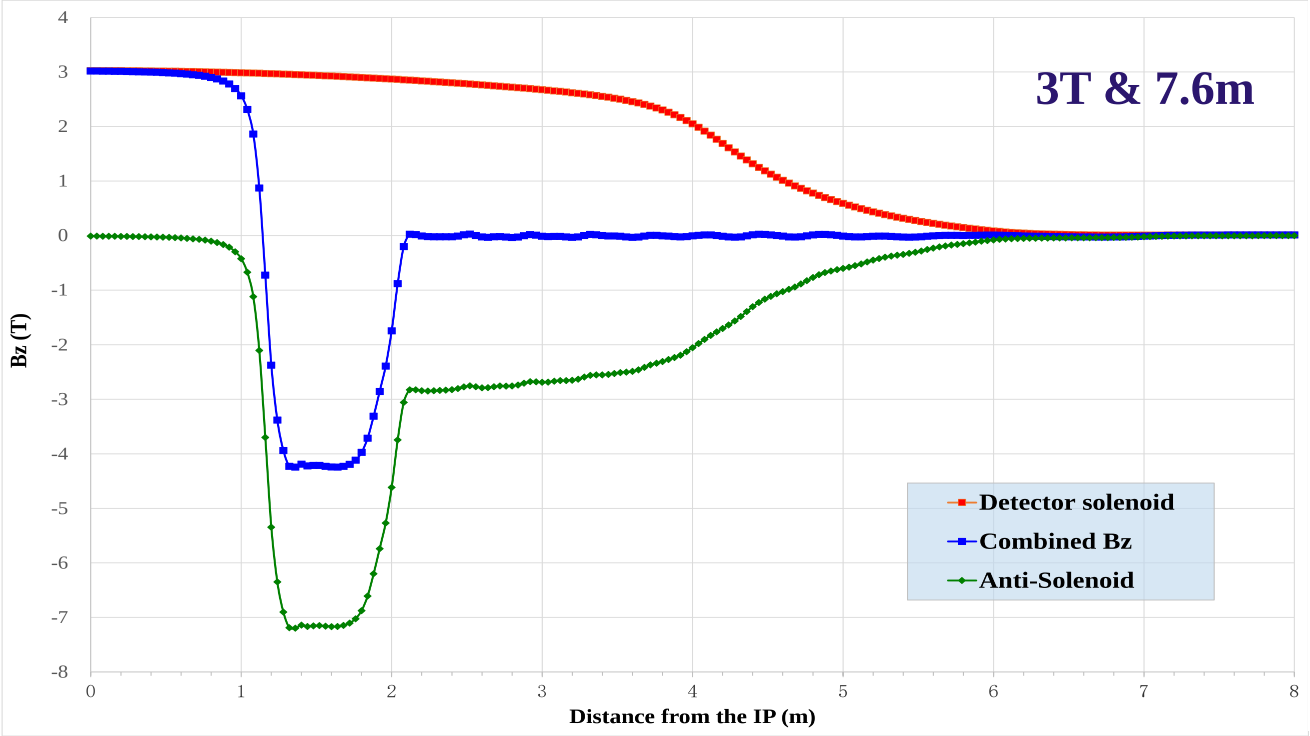
QDa/QDb, QF1 physics design parameters

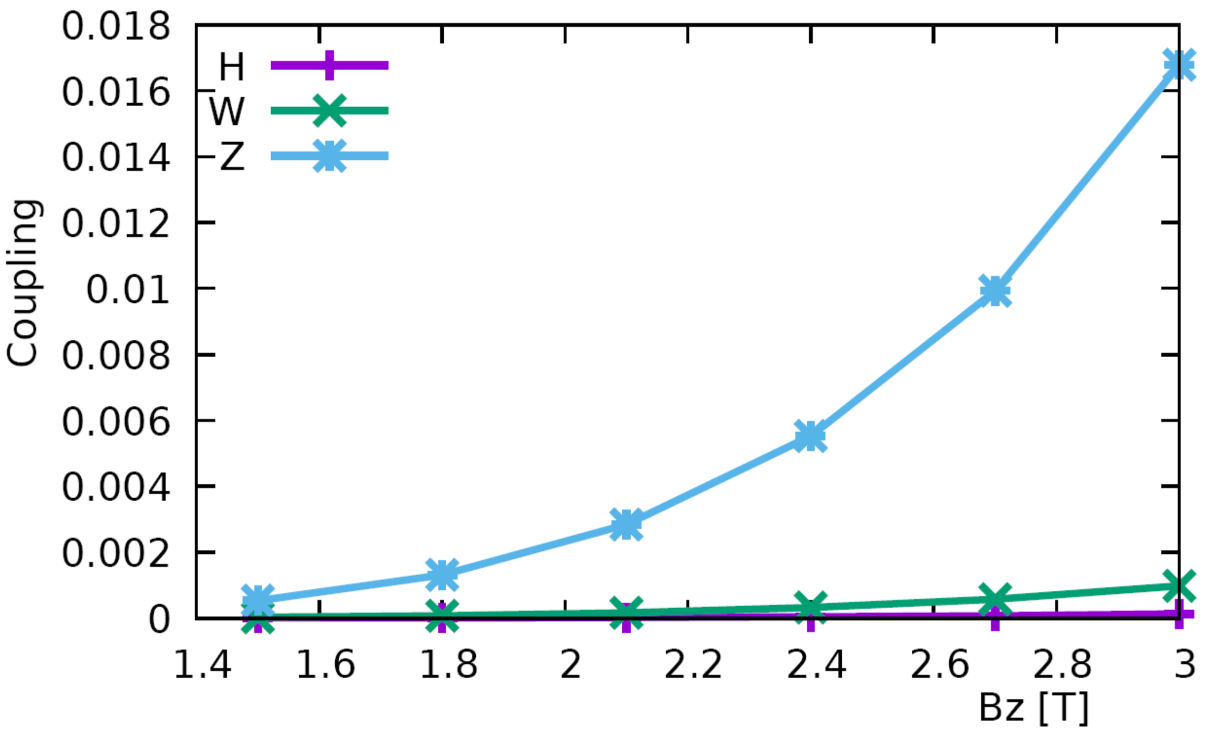
β_y*=1mm, β_x*=0.33m

QDa/QDb	Horizontal BSC 2（$18\sigma_x$+3）	Vertical BSC 2（$22\sigma_y$+3）	e+e- beam center distance
Entrance	10.16/14.38 mm	15.13/19.06 mm	72.61/124.75 mm
Middle	11.78/17.52 mm	17.67/18.97 mm	97.03/149.17 mm
Exit	14.09/22.03 mm	19.00/17.46 mm	122.11/174.26 mm
Good field region	Horizontal 14.09/22.03 mm; Vertical 19.11/19.19 mm		
Effective length	1.5 m		
Distance from IP	2.2/3.78 m		
Gradient	77.5/77.5 T/m		

QF1	Horizontal BSC 2（$18\sigma_x$+3）	Vertical BSC 2（$22\sigma_y$+3）	e+e- beam center distance
Entrance	23.64 mm	16.79 mm	181.85 mm
Middle	29.04 mm	14.72 mm	214.52 mm
Exit	30.91 mm	14.01 mm	247.85 mm
Good field region	Horizontal 30.91 mm; Vertical 16.79 mm		
Effective length	2 m		
Distance from IP	5.51 m		
Gradient	63.4 T/m		

Solenoid compensation





Emittance growth caused by the fringe field of solenoids

- **$\int B_z ds$ 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.

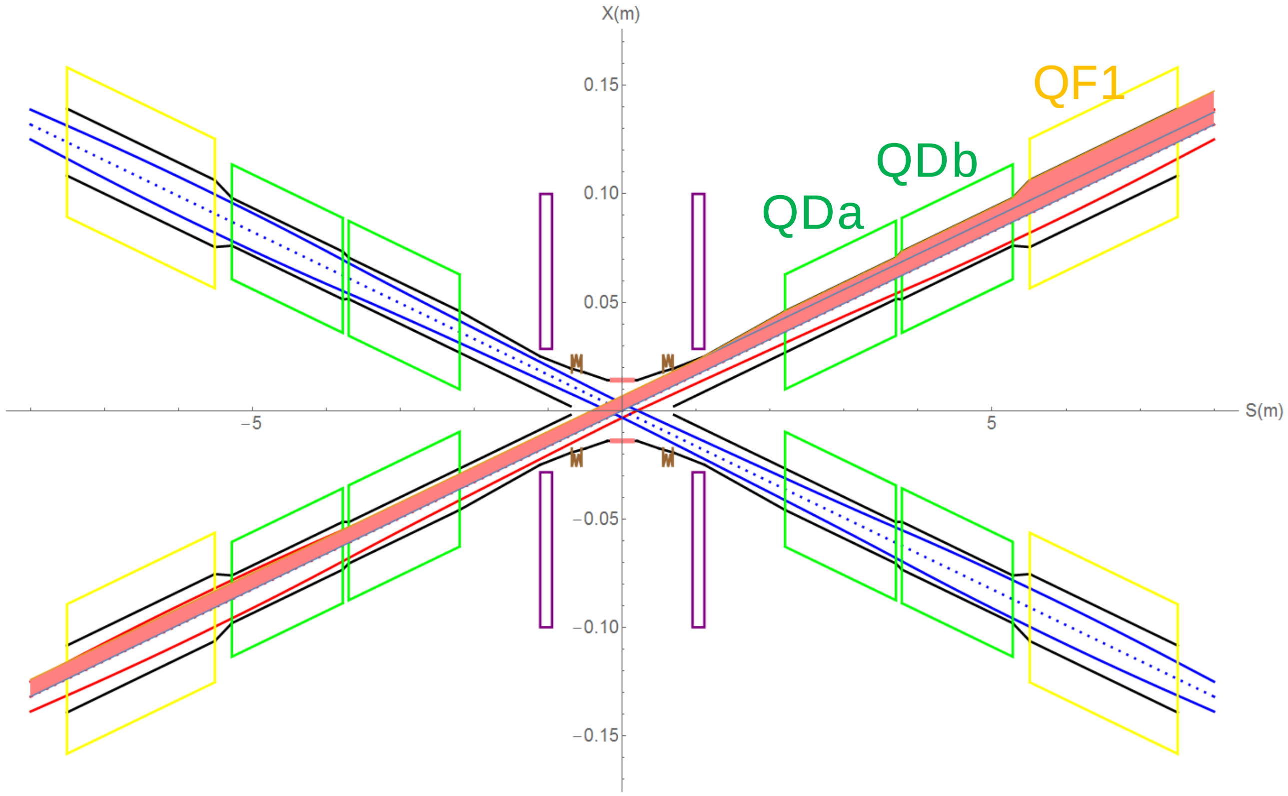
Design emitY/emitX	expected contribution	real contribution
H: 3.6pm/1.21nm (0.3%)	0.36pm	0.14pm (0.01%)
W: 1.6pm/0.54nm (0.3%)	0.16pm	0.47pm (0.09%)
Z: 1.0pm/0.17nm (0.5%)	0.09pm	**2.9pm (1.7%)**

Critical energy of bending magnets in IR

Name	length	angle	Distance from IP	Cirtical energy
BMV01IRU	115.01	-0.00076	83.69	25.3keV
BMV02IRU	68.95	-0.00195	215.28	108.4keV
BMV03IRU	68.95	-0.00187	286.23	103.9keV
BMV1IRU	68.95	0	428.23	0
BMV2IRU	68.95	-0.00352	430.23	195.7keV
BMV3IRU	68.95	-0.00352	503.28	195.7keV
BMV01IRD	75.05	0.00072	57.04	36.6keV
BMV02IRD	44.2	0.00344	174.08	298.3keV
BMV03IRD	44.2	0.00256	220.28	222.0keV
BMV1IRD	44.2	0	268.58	0
BMV2IRD	44.2	0.00537	314.78	465.7keV
BMV3IRD	44.2	0.00537	363.08	465.7keV

SR on IR beam pipe from last bend upstream

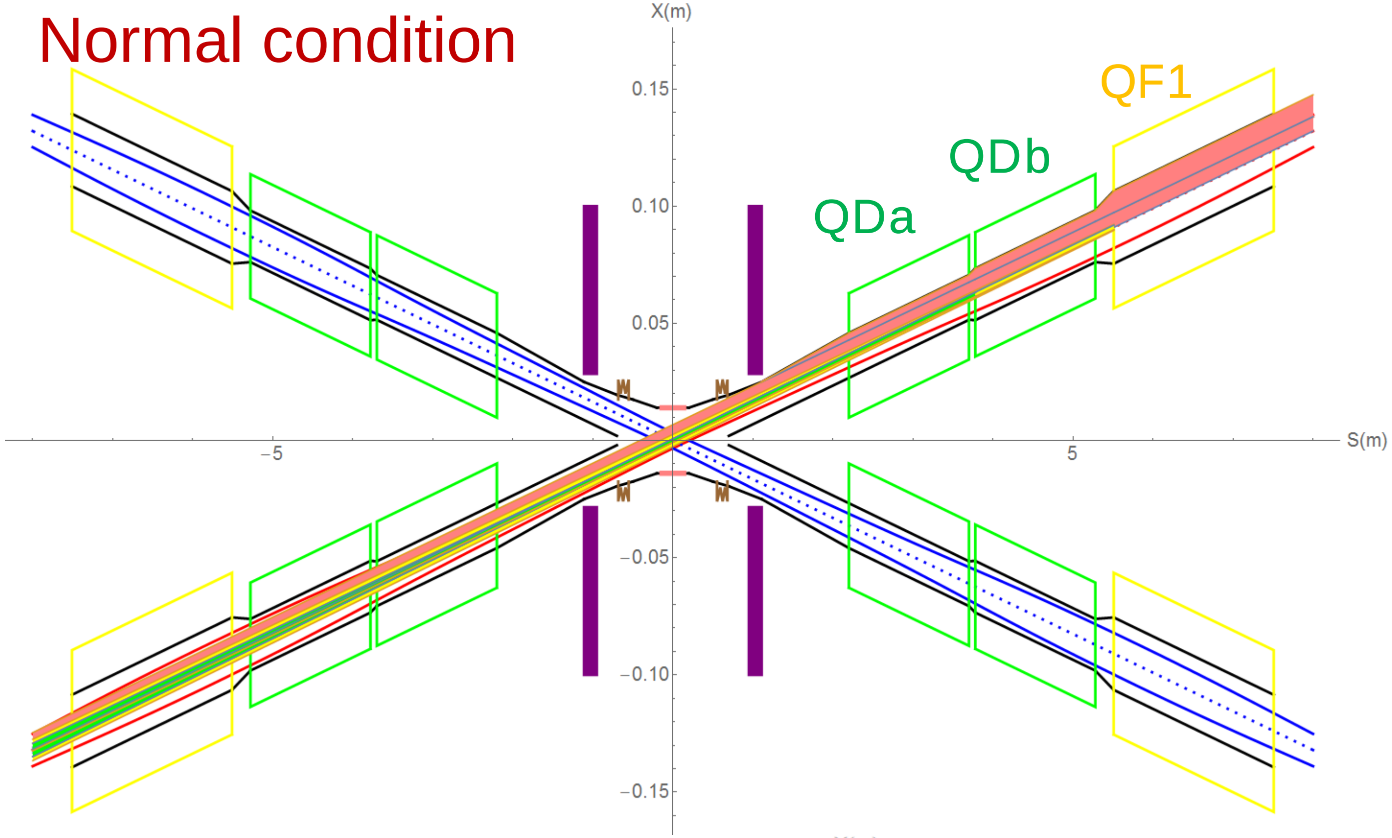
- “Room temperature” beam pipe and conduction cooled superconducting magnet has to be adopted.

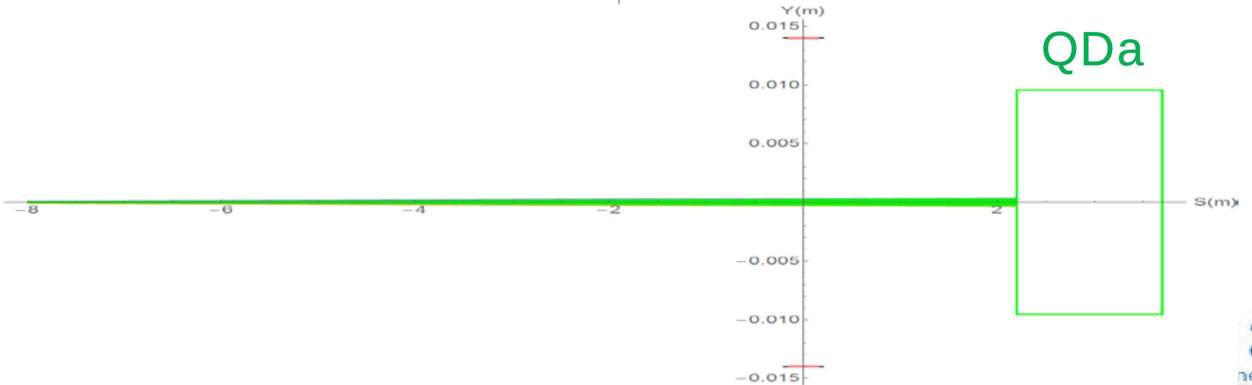


The synchrotron radiation power between exit of Lumical and entrance of QDa is 12.5W, on QDa is 0.75W along 1.5m, on QDb is 0.9W along 1.5m, the region between QDa and QDb is 6.3W(0.08m). SR on QF1 is 1.78W along 2m. The region between QDb and QF1 is 19.6W(0.23m).

SR from last bend upstream of IP and Final Doublet

Normal condition



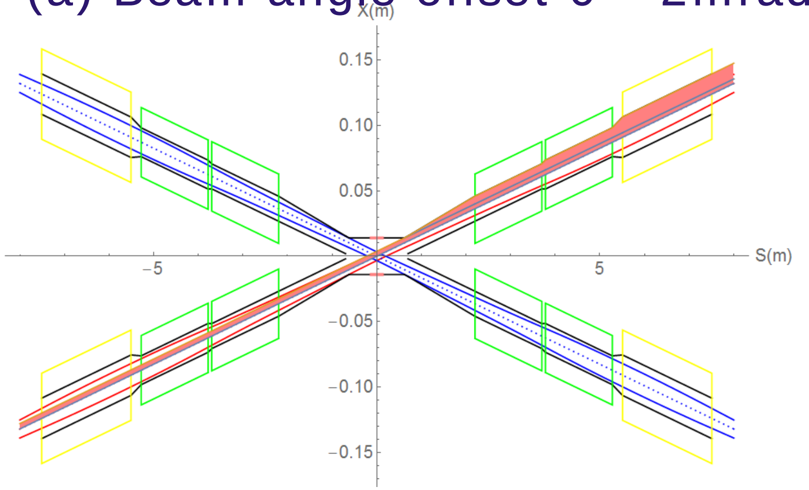


- Last bending magnet generates a fan of SR with power 27.8W contributed by e+ will go through the IP. The critical energy of photons is about 25.3keV. No SR hits directly on the detector beryllium pipe.
- The total SR power generated by the QDa magnet is 80.9W in horizontal and 40.3W in vertical. The critical energy of photons is about 458.7keV in horizontal and 271.2keV in vertical.
- The total SR power generated by the QDb magnet is 242.3W in horizontal and 65.5W in vertical. The critical energy of photons is about 657.9keV and 361.5keV in vertical.
- The total SR power generated by the QF1 magnet is 245.9W in horizontal. The critical energy of photons is about 428.3keV.
- The total SR power generated by the QF1 magnet is 187.5W in vertical. The critical energy of photons is about 613.5keV.

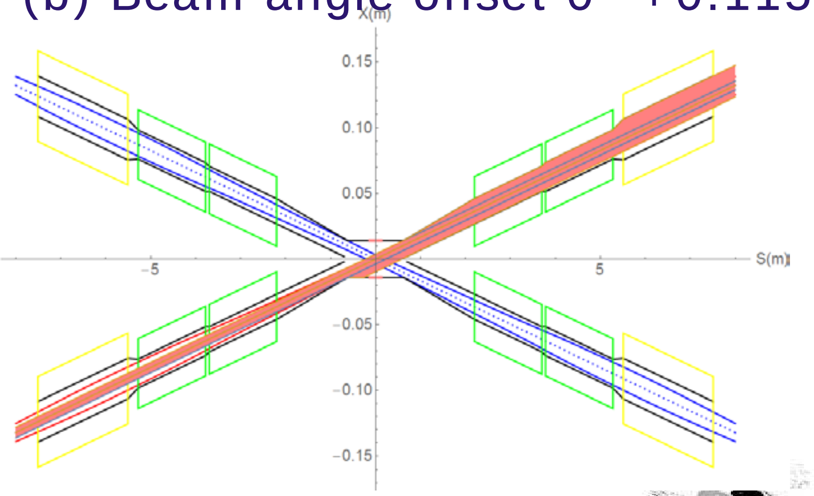
SR from last bending magnet upstream of IP

Extreme condition

(a) Beam angle offset 0~-2mrad



(b) Beam angle offset 0~+0.115mrad



- SR Gaussian distribution with narrow band ~ 0.36mm in width

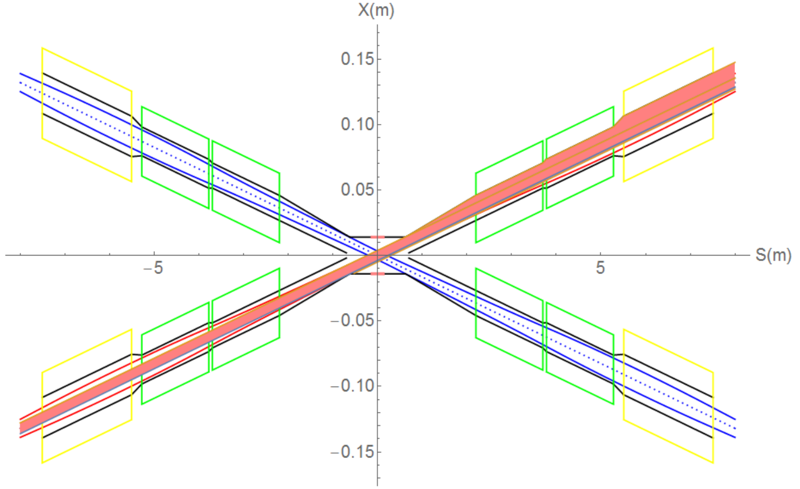
a) When the beam angle moves from 0 to -2mrad, the detector pipe (IP~0.62m) has no SR heat load. 0.62~0.7m beam pipe SR power ~0.76W，average power density~ 26388.89W/m^2. 0.7m~2.2m SR power~23.9W, APD~44259W/m^2.

b) When the beam moves from 0 to 0.115mrad, the detector pipe (IP~0.26m) has no SR heat load. 0.26~0.62m beam pipe SR power ~24.2W，average power density~ 188086W/m^2. 0.62m~0.7m SR power~0.76W, APD~26388W/m^2. 0.7m~2.2m SR power~54.5W, APD~100925W/m^2

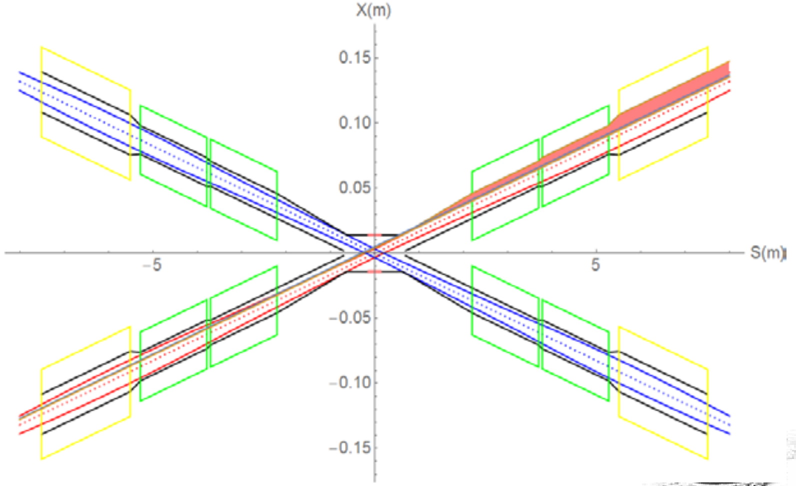
SR from last bending magnet upstream of IP

Extreme condition

(c) Beam position offset 0~+5mm



(d) Beam position offset 0~-5mm



➢ SR Gaussian distribution with narrow band ~ 0.36mm in width

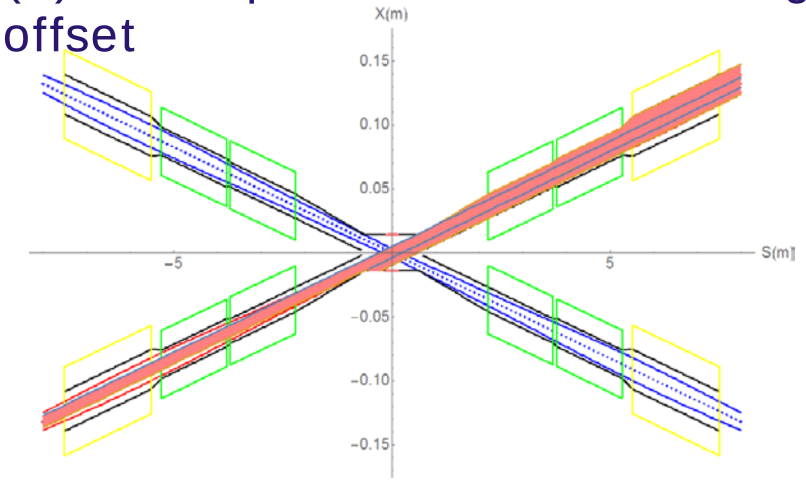
c) Since shortest distance at 0.62 to beam axis, the upstream SR will be prevented, no SR thermal load from IP to 0.62m. The thermal load of other vacuum chamber no change (same as normal conditions), parameters of dipole no change, but SR fan will move up.

d) Since shortest distance at 0.62 to beam axis, the upstream SR will be prevented, no SR thermal load from IP to 0.62m. The thermal load of other vacuum chamber no change (same as normal conditions), parameters of dipole no change, but SR fan will move down.

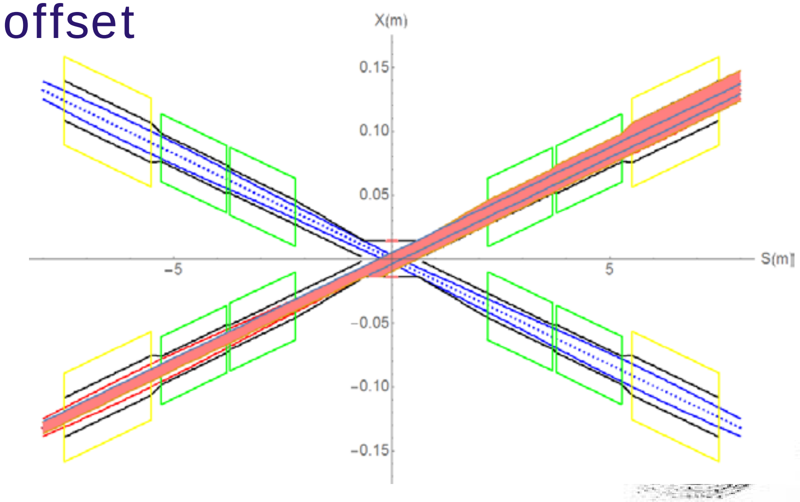
SR from last bending magnet upstream of IP

Extreme condition

(e) Beam position 0~+5mm+angle offset



(f) Beam position 0~-5mm+angle offset



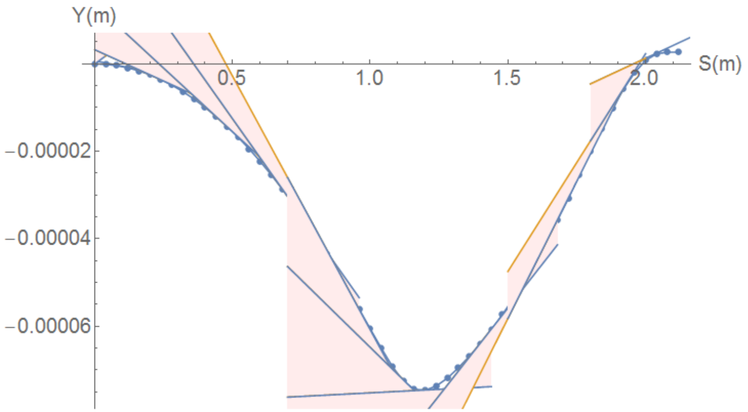
- SR Gaussian distribution with narrow band ~ 0.36mm in width

e) When the beam position offset ~-5mm, SR will hit on the beam pipe with +0.055mrad beam angle. the detector pipe (IP~0.266m) has no SR heat load. 0.266~0.62m beam pipe SR power ~23.85W，average power density~ 187199W/m^2. 0.62m~0.7m SR power~0.79W, APD~27430W/m^2.

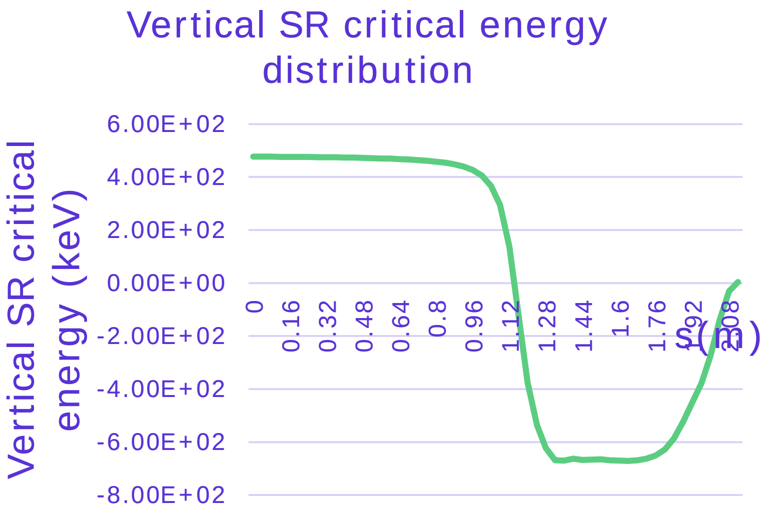
f) When the beam position offset ~+5mm, SR will hit on the beam pipe with +0.175mrad beam angle. the detector pipe (IP~0.259m) has no SR heat load. 0.259~0.62m beam pipe SR power ~24.5W，average power density~ 188571W/m^2. 0.62m~0.7m SR power~0.74W, APD~25694W/m^2.

SR from solenoid combined field

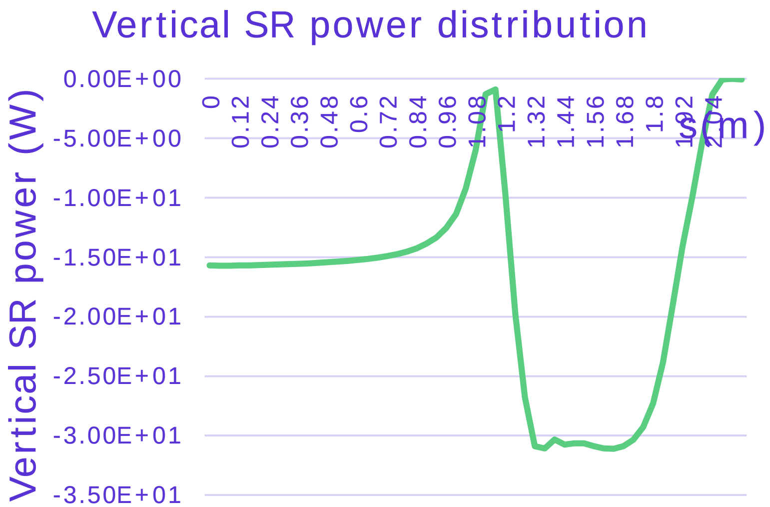
- Horizontal trajectory will coupled to the vertical
- Due to the sol+anti-sol field strength quite high, maximum~4.24T, transverse magnetic field component is quite high.
- SR from vertical trajectory in sol+anti-sol combined field should be taken into account.



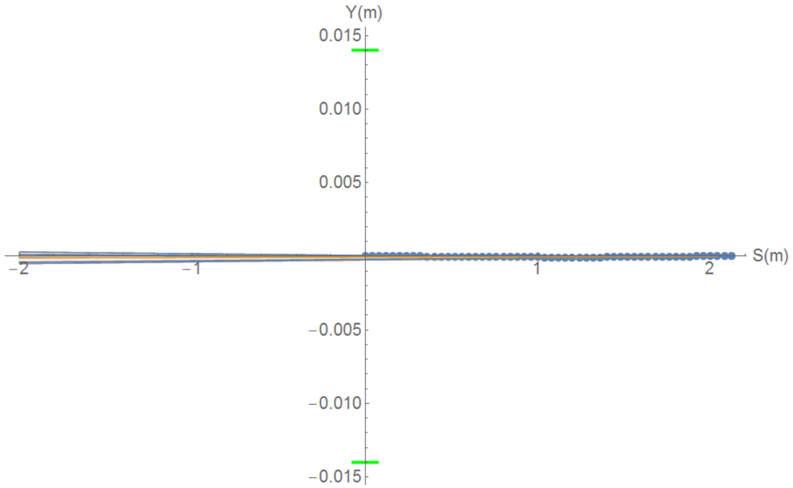
- SR fan is focused in a very narrow angle from -116urad to 131urad
- SR will not hit Berryllium pipe, and not background to detector.
- SR will hit the beam pipe ~213.5m downstream from IP
- Water cooling is needed.



Maximum: 670keV



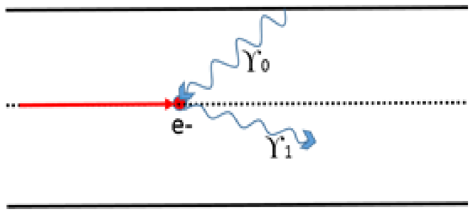
Maximum: 31W



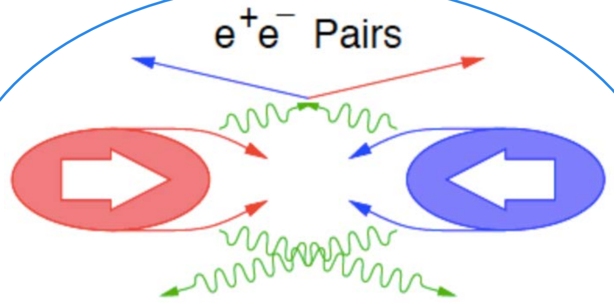
CEPC beam lifetime

	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	

Beam loss Backgrounds at CEPC



Beam-Thermal photon scattering



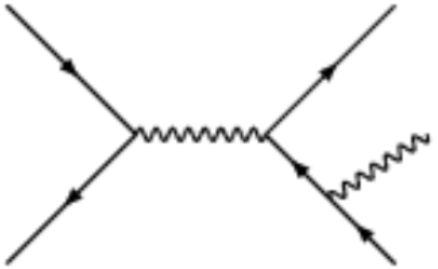
Beamstrahlung

IP1

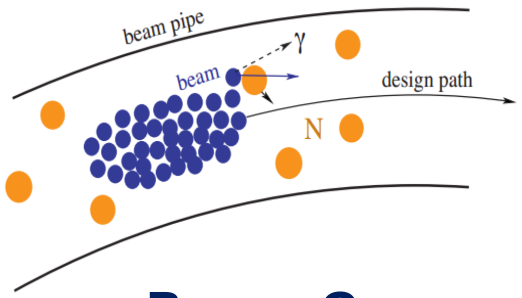
218 bunches
Revolution frequency: **2997**Hz
1.5×10^{11} particles/Bunch
L: $5.2\times 10^{34} cm^{-2}s^{-1}$

IP3

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



Radiative Bhabha scattering

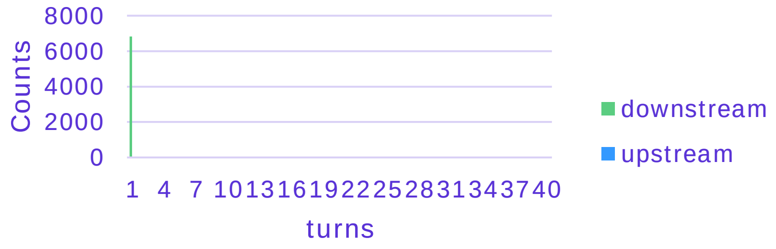


Beam-Gas Scattering

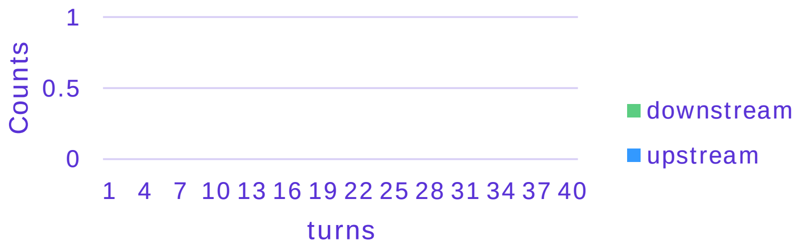
Beam loss in IR

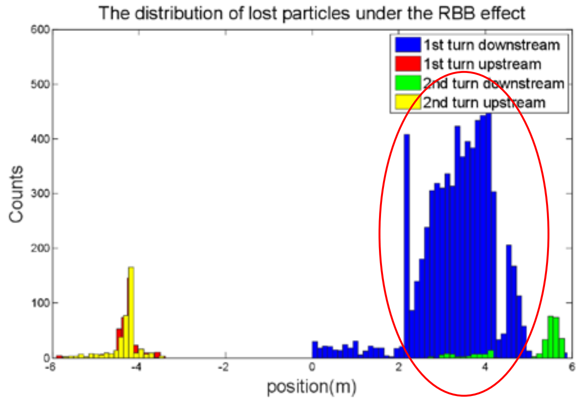
- Beam loss reduced to very low level with collimators for RBB and BS.

Lost particles due to RBB in turns with collimators half width x=5mm for Higgs



Lost particles due to BS in turns with collimator half width x=5mm for Higgs





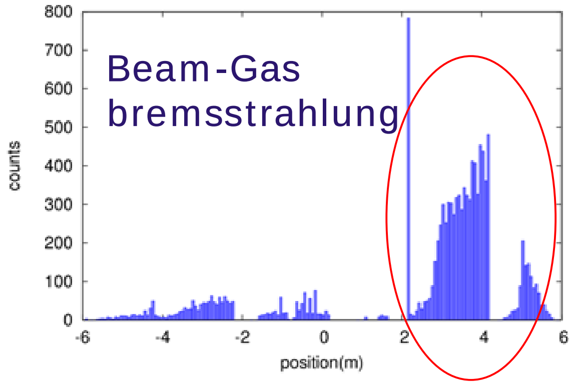
- It is unlikely to use pure tungsten, which is too brittle.
- WNiFe and WNiCu are two kinds of alloys that can be made. WNiCu is non-magnetic, but it is difficult to make this alloy too long. It must be welded in sections, with each section no more than 1m.
- For the 6m long IR beam pipe, there will be many welds.
- Tungsten alloy is made by powder pressing. It has certain machining performance and welding performance (brazing). The vacuum performance is unknown.

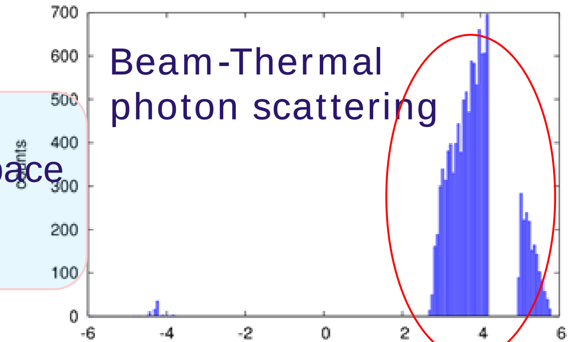
Two solutions

may cause SC magnet quench

1. Tungsten IR beam pipe,
2. add shielding of the FF quadrupole coils.

IR vacuum ~3E-10 torr, to improve the IR vacuum:
1.use as many vacuum pumps as possible, need more space
2. coat the inner surface of the vacuum chamber with getter film.

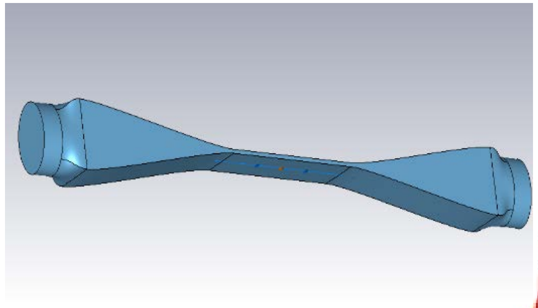


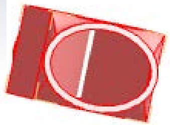


Collimator design

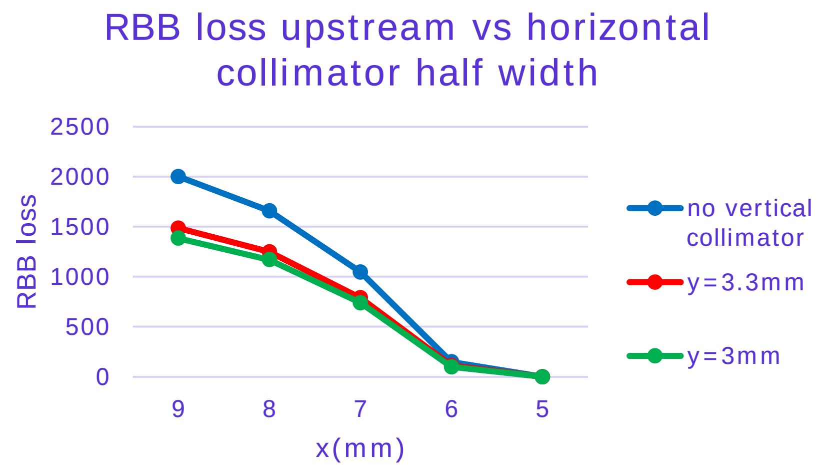
- Beam stay clear region: 18 σ_x+3mm, 22 σ_y+3mm
- Impedance requirement: slope angle of collimator < 0.1
- To shield big energy spread particles, phase between pair collimators: $\pi/2+n*\pi$
- Collimator design in large dispersion region: $\sigma=\sqrt{\varepsilon\beta + (D_x\sigma_e)^2}$

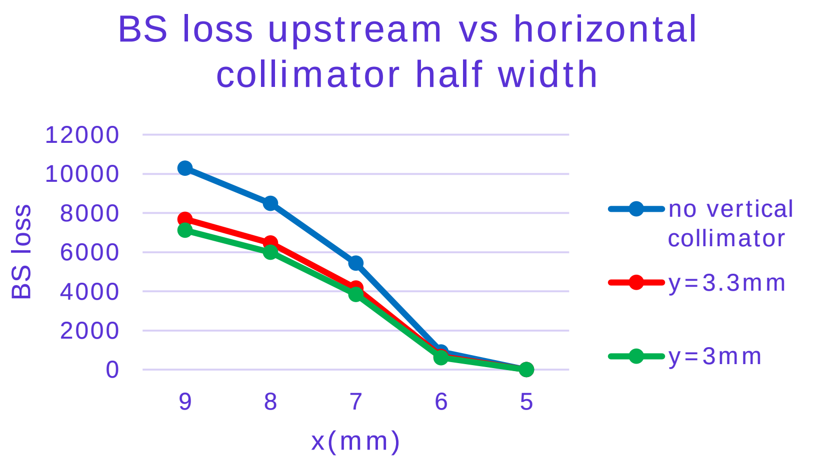
name	Position	Distance to IP/m	Beta function/m	Horizontal Dispersion/m	Phase	BSC/2/m	Range of half width allowed/mm
APTX1	D1I.1897	2139.06	113.83	0.24	356.87	0.00968	2.2~9.68
APTX2	D1I.1894	2207.63	113.83	0.24	356.62	0.00968	2.2~9.68
APTX3	D1O.10	1832.52	113.83	0.24	6.65	0.00968	2.2~9.68
APTX4	D1O.14	1901.09	113.83	0.24	6.90	0.00968	2.2~9.68
APTX5	DMBV01IRU0.492	31	196.59	0	362.86	0.01178	2.9~11.78



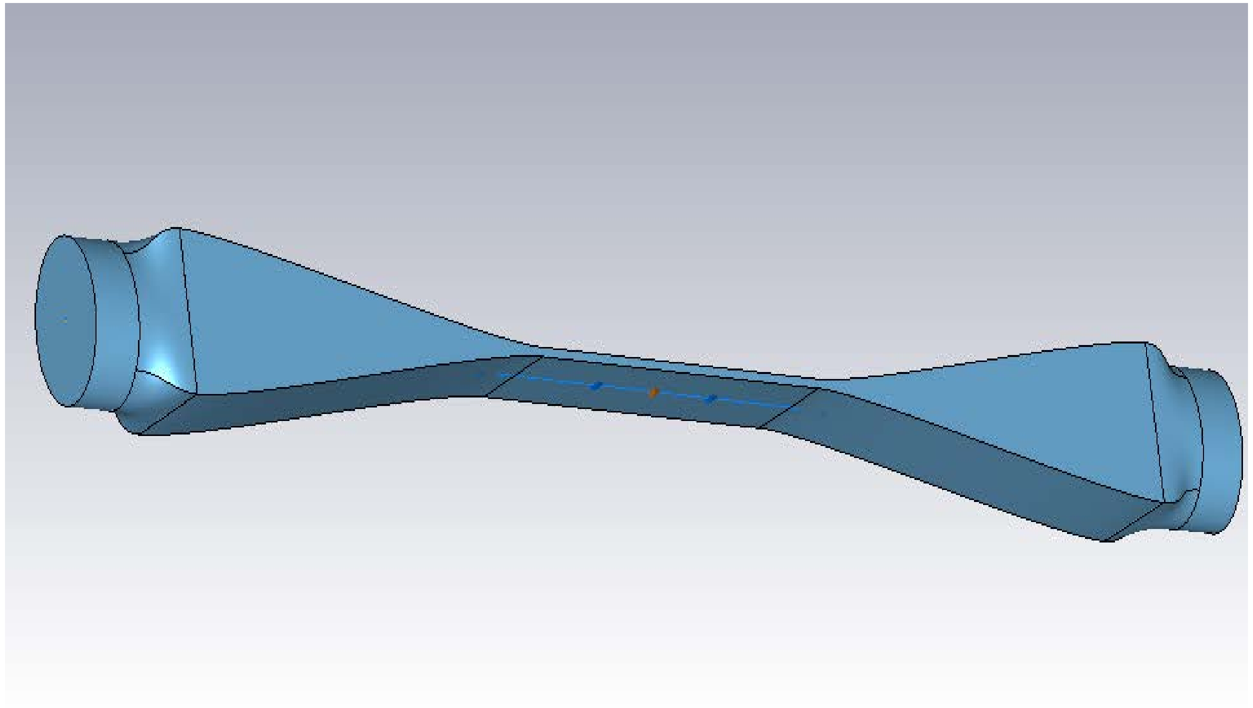


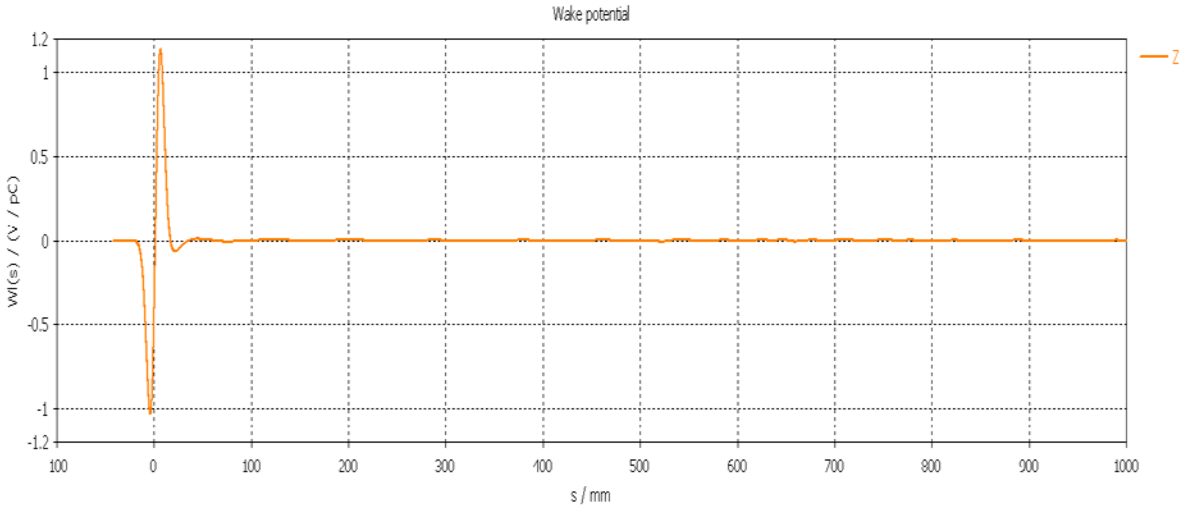
- horizontal collimator half width 5mm(13σ_x)
- The collimators will not have effect on the beam quantum lifetime.

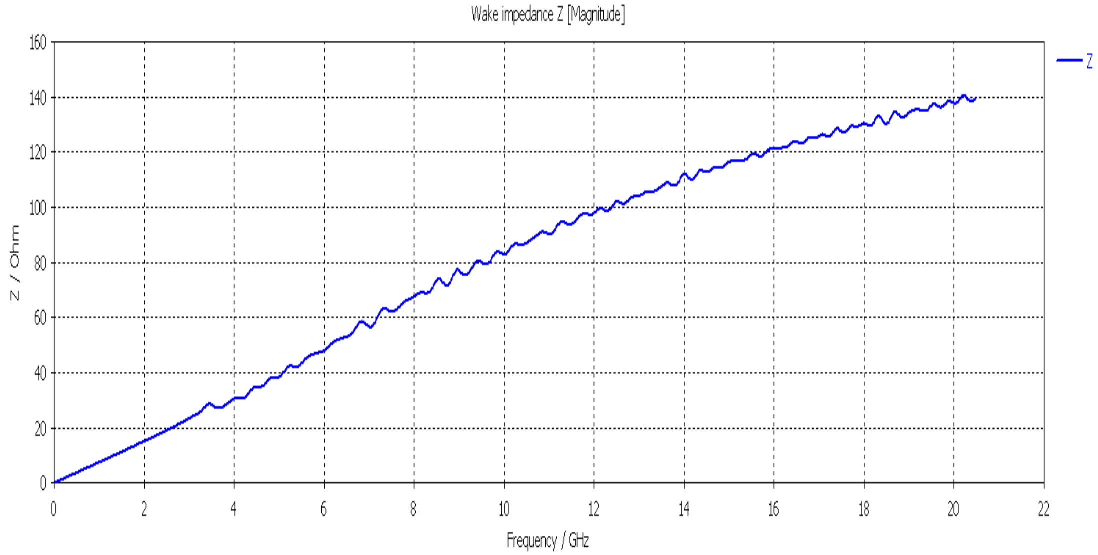




Collimator impedance

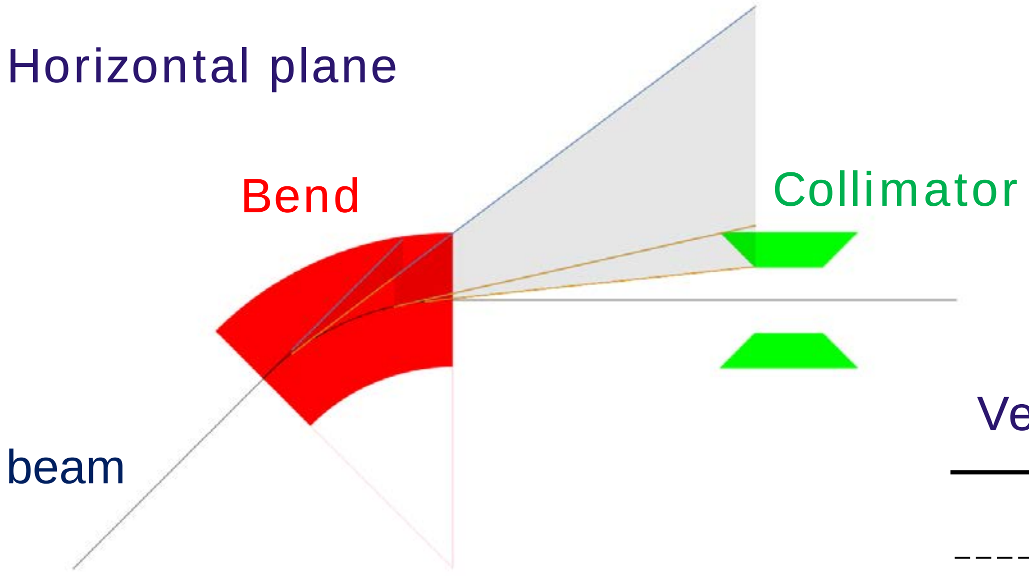


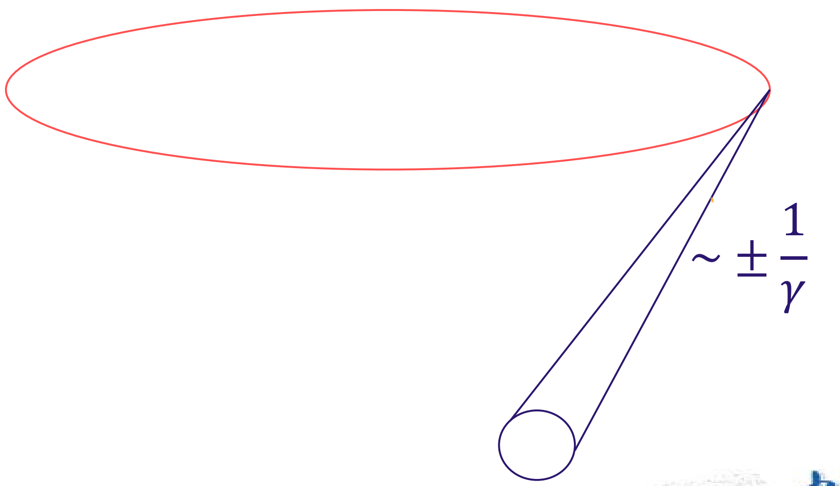


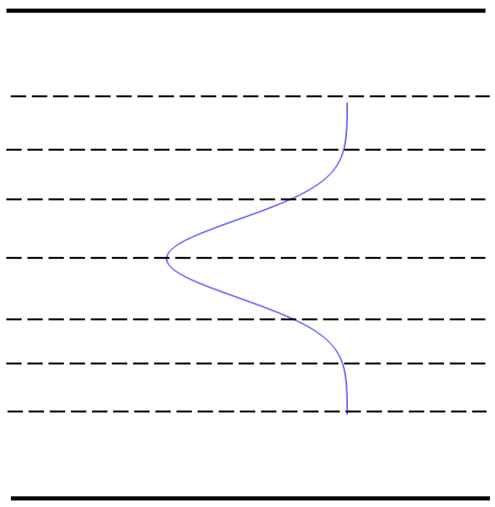


Wake Integration type : Indirect Interfaces
Simulated wake length : 1000 mm
Wake shift x : 0 mm
Wake shift y : 0 mm
Wake-Loss-Factor : 1.403765e-001 V/pC
Entry interface at z-coordinate: -3.851471e+002 mm (grid-index: 102)
Exit interface at z-coordinate : 3.851471e+002 mm (grid-index: 4681)

Synchrotron radiation at collimator



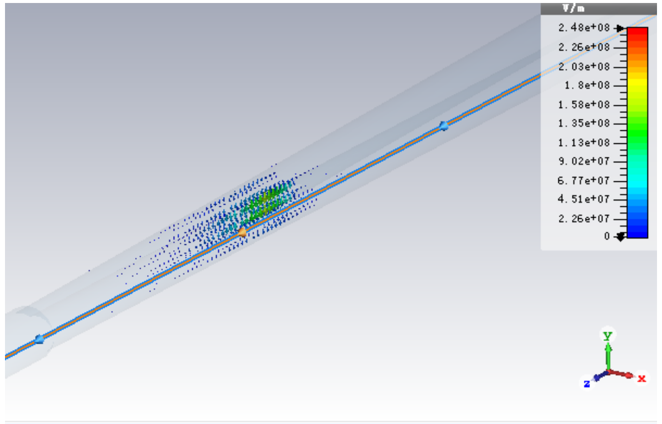


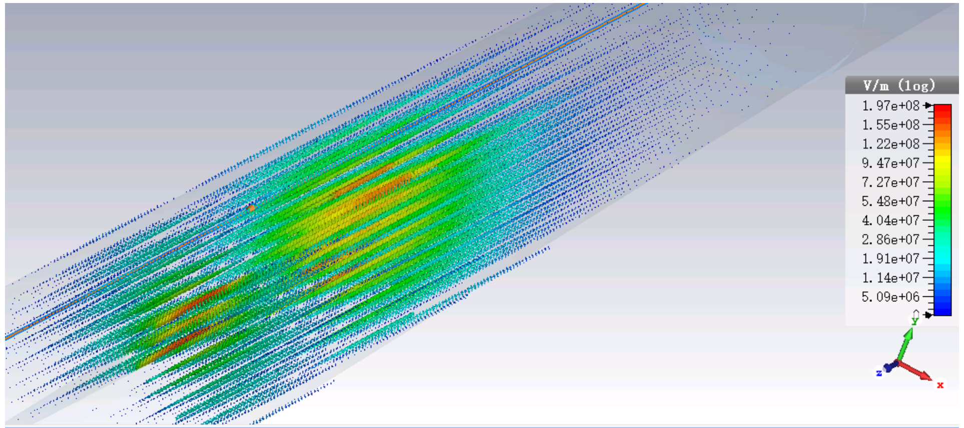


$$\sigma'_y = \sqrt{\sigma'^2_{y\beta} + \sigma^2_\theta}$$

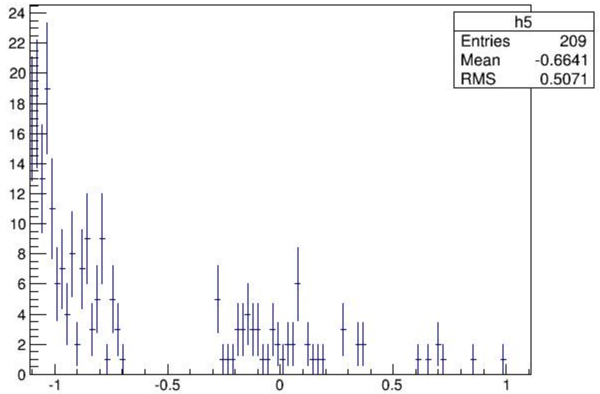
- ✓ Synchrotron radiation from the upstream bending magnet in the ARC can contribute to the heat load of the collimators.
- ✓ SR hit collimators: critical energy~357keV, power~7.7kW.
- ✓ SR uniform distribution in horizontal plane and Gaussian distribution in vertical plane.
- ✓ Total vertical angular divergence of SR photon beam~ 8.52urad.

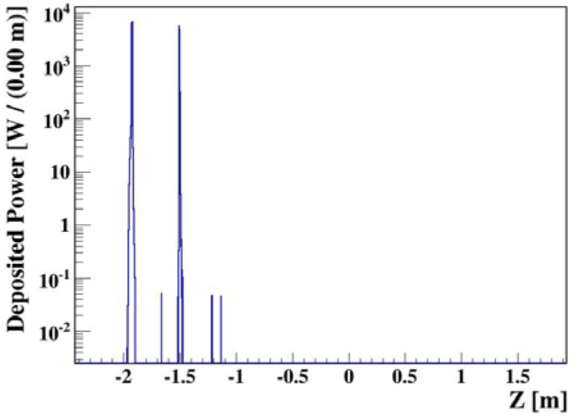
HOM absorber



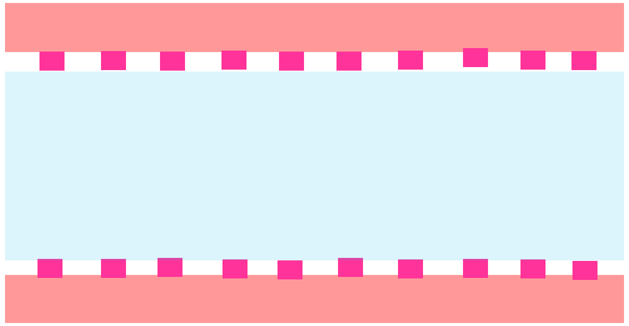


- HOM at crotch point (z~±700mm)
- HOM frenquency 10GHz, close to cut-off frequency (decided by beam pipe aperture).
- HOM power ~3kW.
- This mode is trapped mode.
- HOM absorber is needed，water cooling system considered.





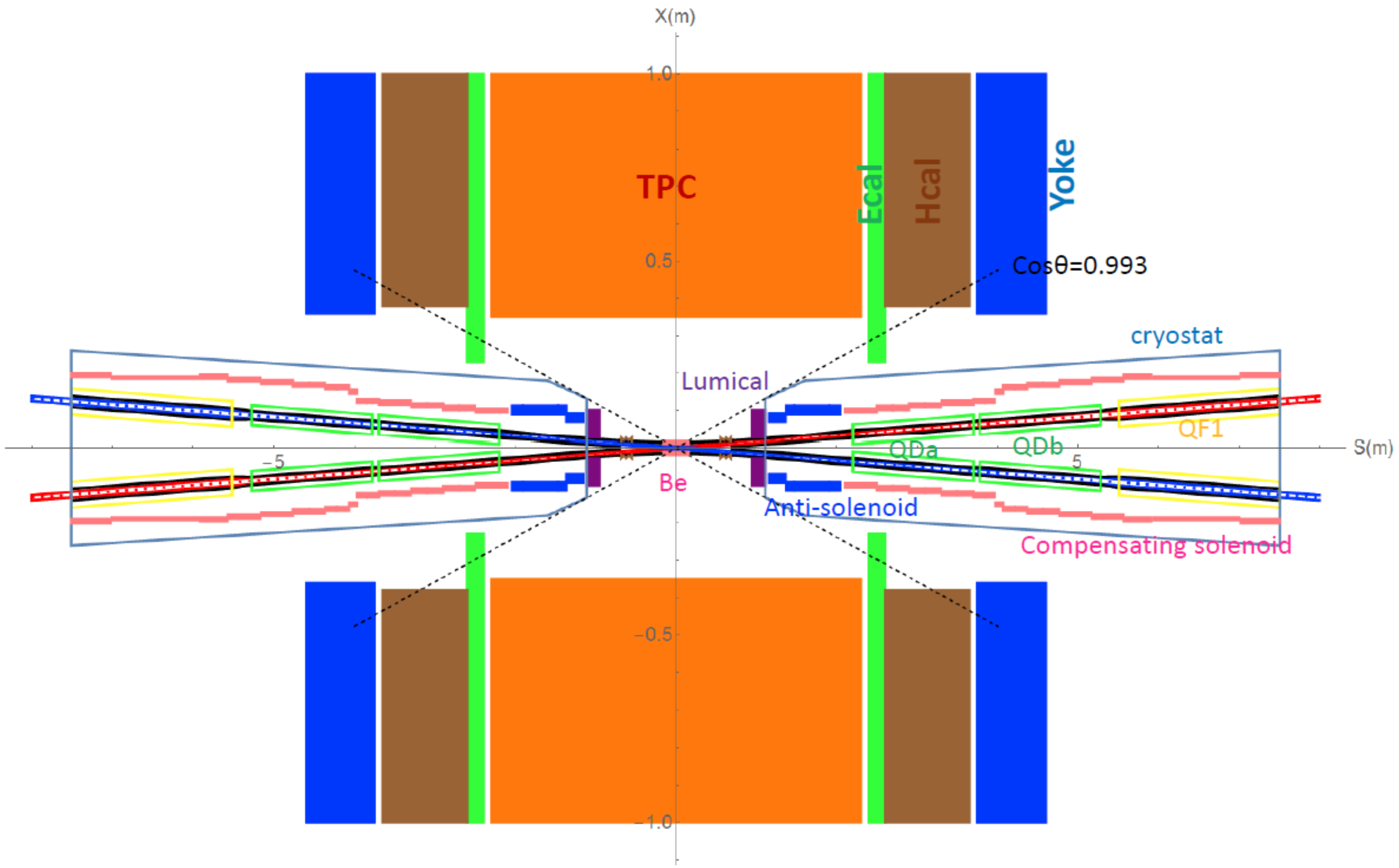
Beam pipe



- ✓ Synchrotron radiation from Final doublet magnets and reflection part from mask，~mW power.
- ✓ SR resistance acceptable for HOM absorber

- HOM absorber design: inner surface of the beam pipe is grooved and coated with absorbing material, and the outer surface of the beam pipe is water cooled.
- Distance from IP is around 70cm just before the crotch point.
- Impedance

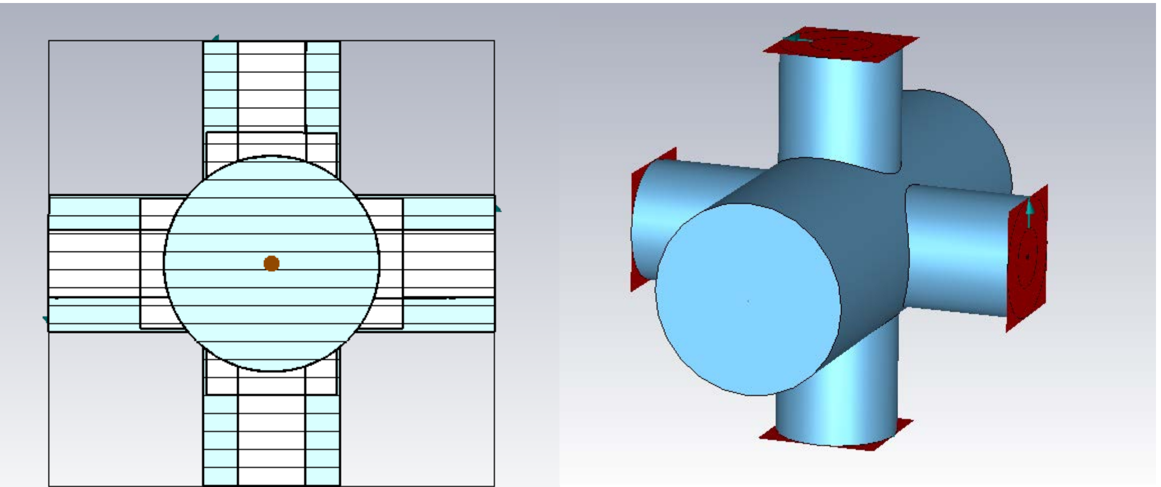
IP BPM



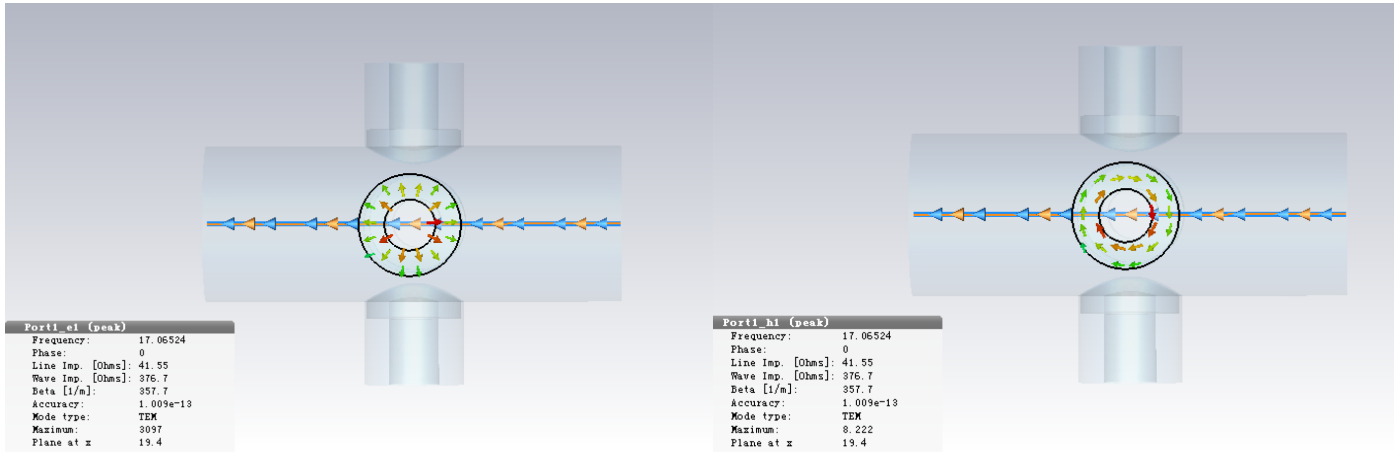
- Considering response time and calibration difficulty, two 4 button electrodes BPM at each side of CEPC IR is adopted.
- Most of CEPC IR beam pipe are cylinder or conic, only the part from 70cm to 95cm is special shape.
- There is a bellows for the requirements of installation in the crotch region, located about 0.7 m from the IP. IP BPM will be installed at 80cm from the IP in the double pipe part.
- Beam pipe size：diameter 18.74mm
- Bunch length：2.68mm
- Single bunch charge：24nC

4 button electrodes BPM

4 button electrodes structure

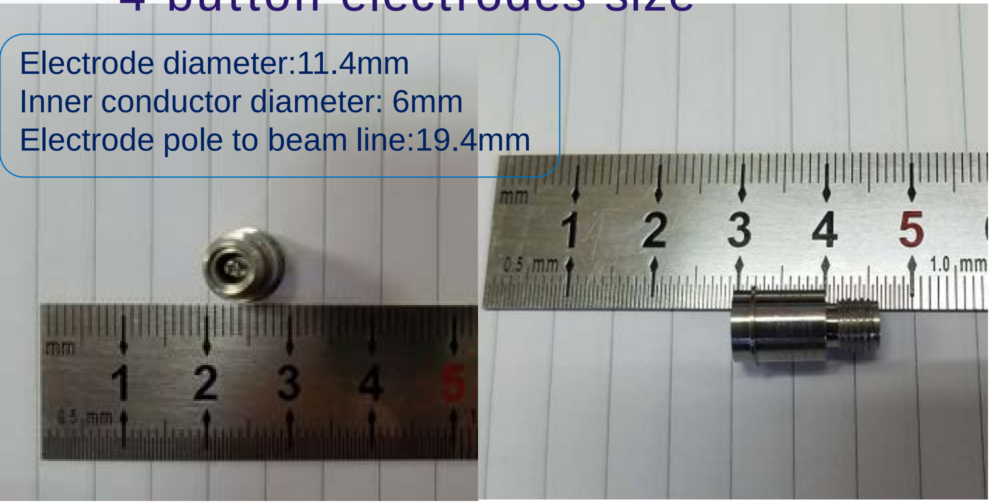


Electromagnetic field at electrodes

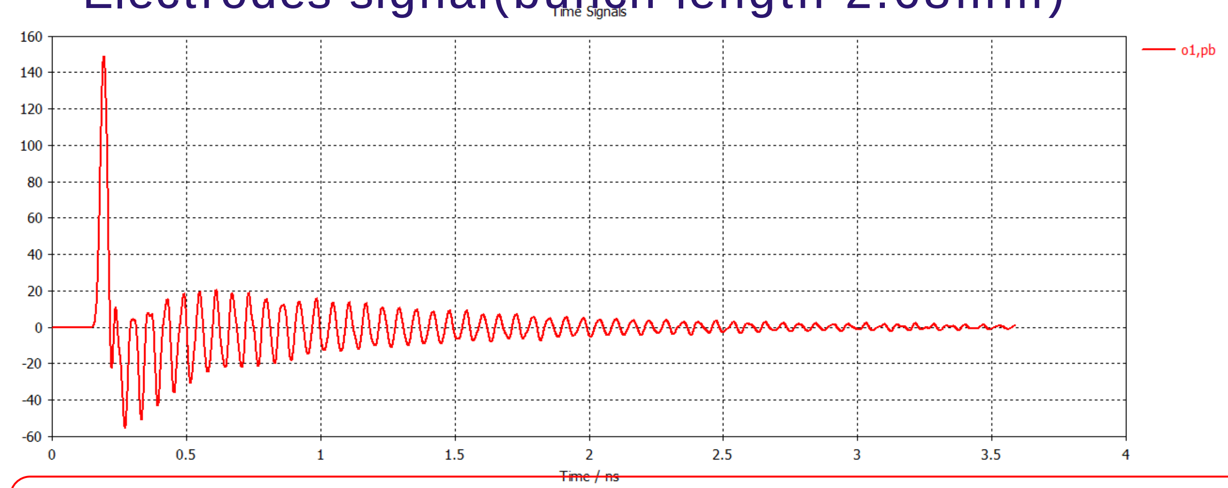


4 button electrodes size

Electrode diameter:11.4mm
Inner conductor diameter: 6mm
Electrode pole to beam line:19.4mm



Electrodes signal(bunch length 2.68mm)



Due to the short bunch length, signal has many resonance hump, signal amplitude proportional to the bunch charge.

Size and signal intensity can be satisfied by CEPC MDI requirement.

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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.
- Synchrotron radiation effect on machine is evaluated.
- Beam lifetime are estimated, beam loss effect on machine and solutions.
- Collimators are designed in the ARC and interaction region. Beam loss have disappeared in the upstream of IP for both Higgs and Z factory.
- Synchrotron radiation and impedance are taken into account for collimators.
- HOM of IR beam pipe has been simulated, water cooling and synchrotron radiation were considered and HOM absorber is under design.
- IP BPM under design.

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Thanks