CEPC MDI Issues

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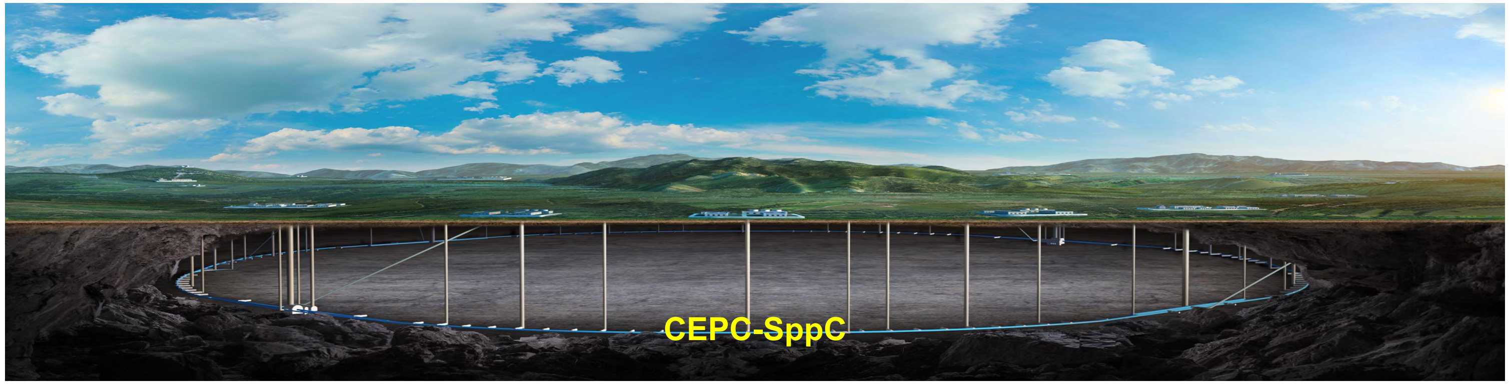
IHEP

On behalf of CEPC MDI Group



CEPC Workshop, US edition, Chicago University, USA

Sept. 16-18, 2019

Outline

- Historical review of e+e- circular coliders
- Circular e+e- collider design principles and methds
- CEPC status
- SppC status
- CEPC-SppC R&D
- CEPC-SppC siting and civil engineering
- CEPC Science city plan
- CEPC collaborations
- Summary

Outline

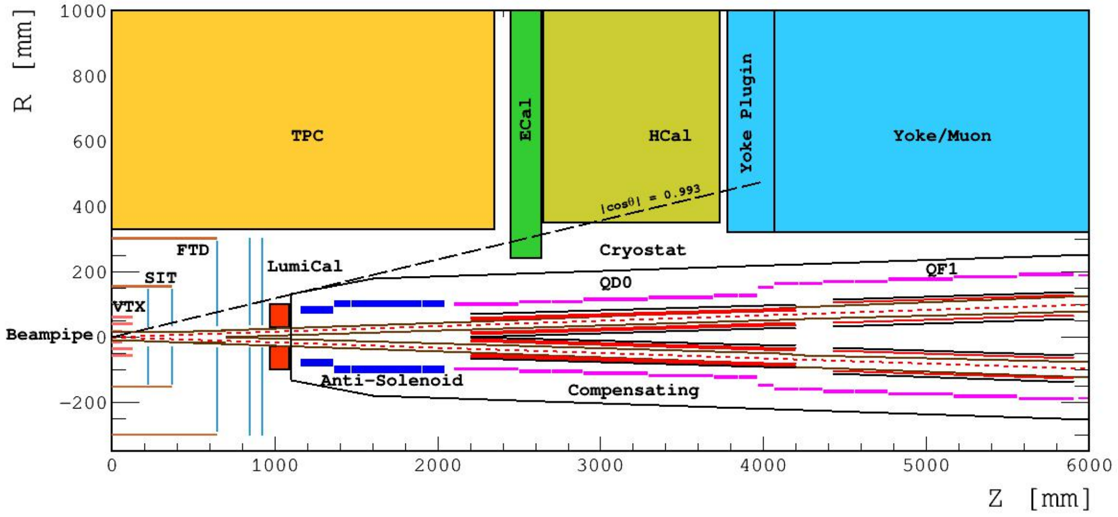
- MDI layout and IR design
- IR Superconducting magnets
- Synchrotron radiation
- Beam loss background
- Collimator design
- HOM absorber
- Mechanics and assembly
- SC magnet supporting system
- IP BPM
- Summary

CEPC CDR Parameters

	Higgs	*W*	*Z*（*3T*）	*Z*（*2T*）
Number of IPs	2			
Beam energy (GeV)	**120**	**80**	**45.5**	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	**242 (0.68μs)**	**1524 (0.21μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**16.5**	
Bending radius (km)	10.7			
Momentum compact (10^{-5})	1.11			
β function at IP β_x^* / β_y^* (m)	**0.36/0.0015**	**0.36/0.0015**	**0.2/0.0015**	**0.2/0.001**
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.031/0.109	0.013/0.106	0.0041/0.056	0.0041/0.072
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	3.26	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.54	0.75	**1.94**	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	**1.35**	**0.4**	**0.23**	
Energy acceptance by RF (%)	2.06	1.47	1.7	
Photon number due to beamstrahlung	0.1	0.05	0.023	
Lifetime _simulation (min)	100			
Lifetime (hour)	**0.67**	**1.4**	**4.0**	**2.1**
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP *L* (10^{34}cm^{-2}s^{-1})	**2.93**	**10.1**	**16.6**	**32.1**

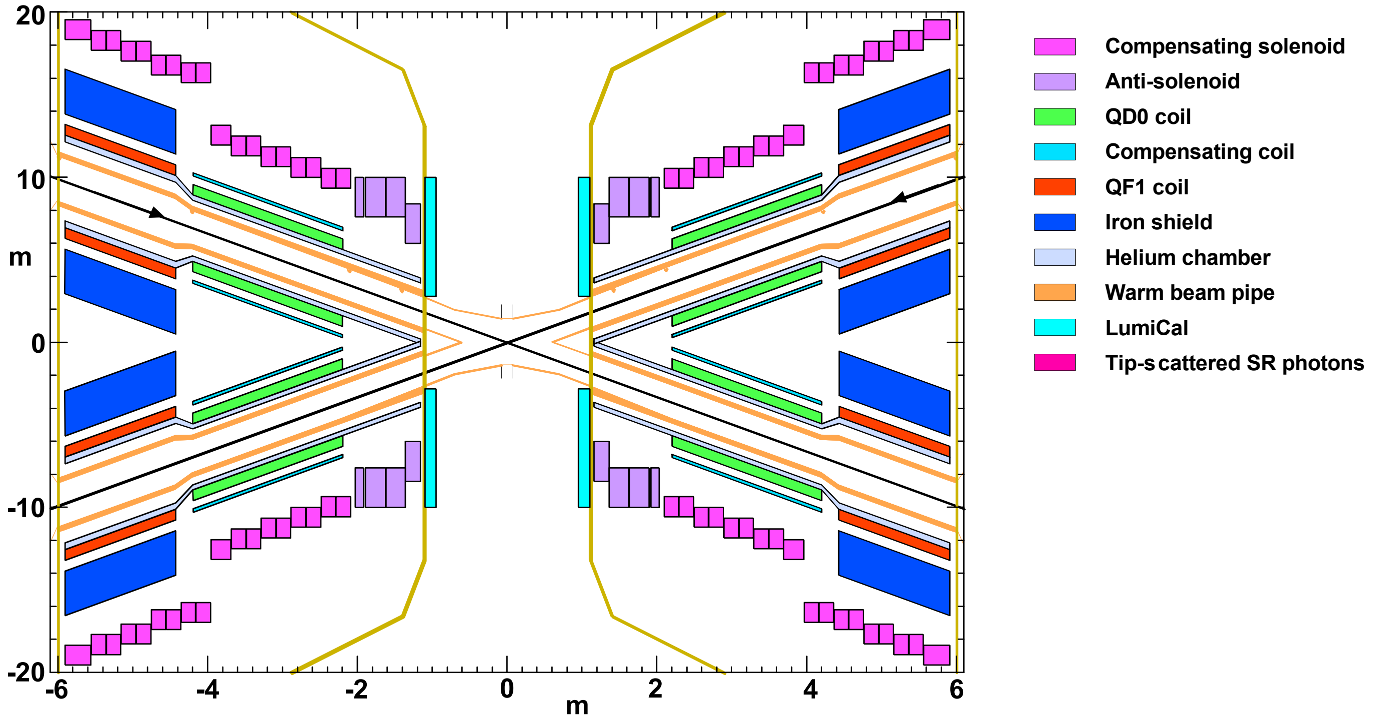
MDI Layout and IR Design

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.

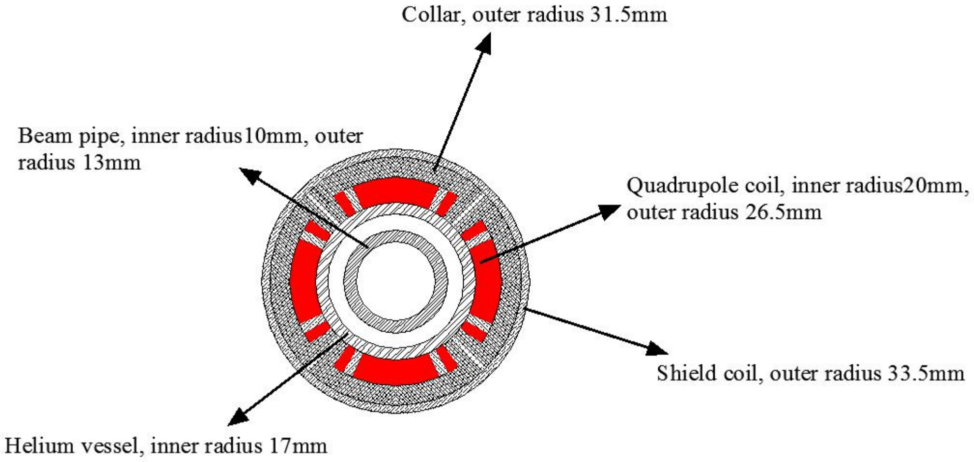
MDI Parameters

	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˚												
QD0		3.2T	136T/m		2m	19.51mm	72.61mm	40mm	53mm	1.3MeV	527keV	639W	292W
QF1		3.8T	110T/m		1.48m	26.85mm	146.2mm	56mm	69mm	1.6MeV	299keV	1568W	74W
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					±7cm			28mm					
Last B upstream	67.66~161.04m			1.1mrad	93.38m					45keV			
First B downstream	46.06~107.04m			1.54mrad	60.98m					97keV			
Beampipe within QD0					2m							2.9W	
Beampipe within QF1					1.48m							3.1W	
Beampipe between QD0/QF1					0.23m							36.2W	

IR Superconducting Magnets-1

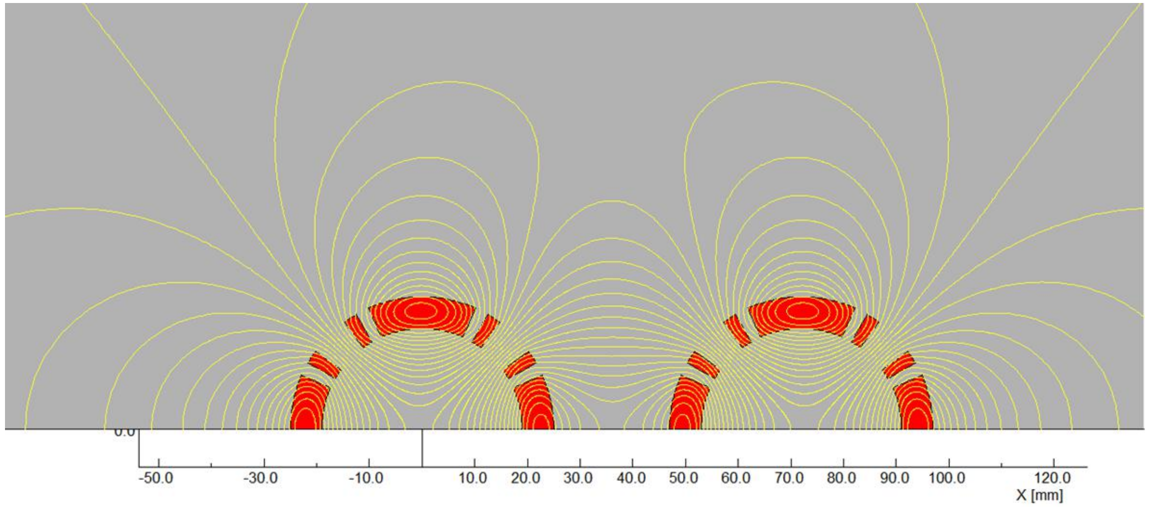
Superconducting QD coils

Rutherford NbTi-Cu Cable

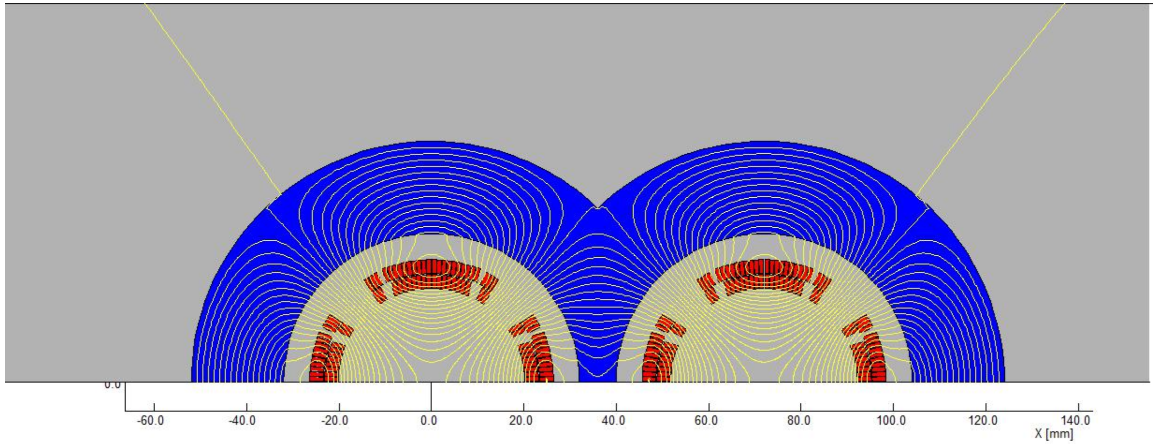


Single aperture of QD0
(Peak field 3.2T)

Two options w/o iron yoke.



Iron option for QD0 is investigated.



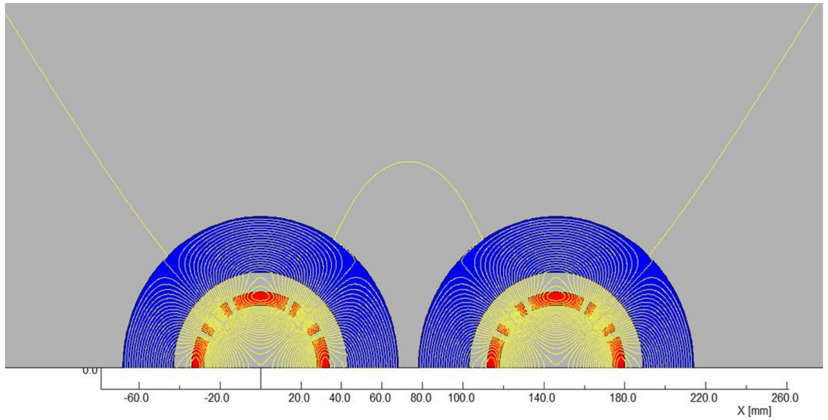
Room-temperature vacuum chamber with a clearance gap of 4 mm

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

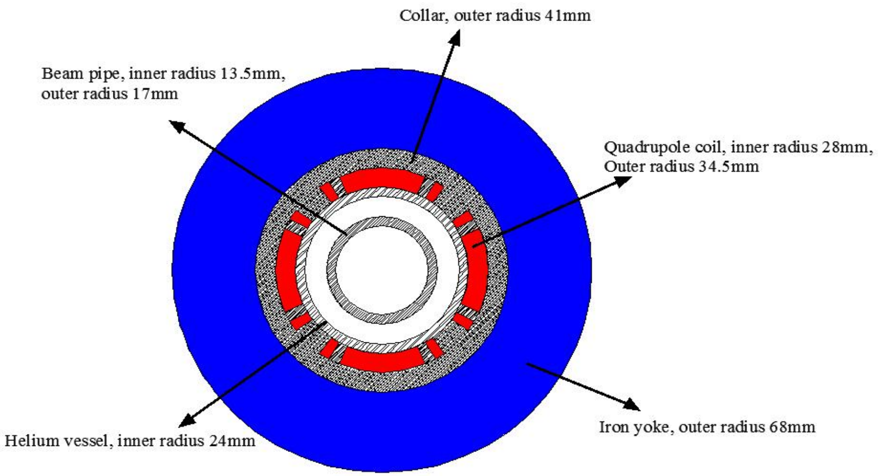
IR Superconducting Magnets-2

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

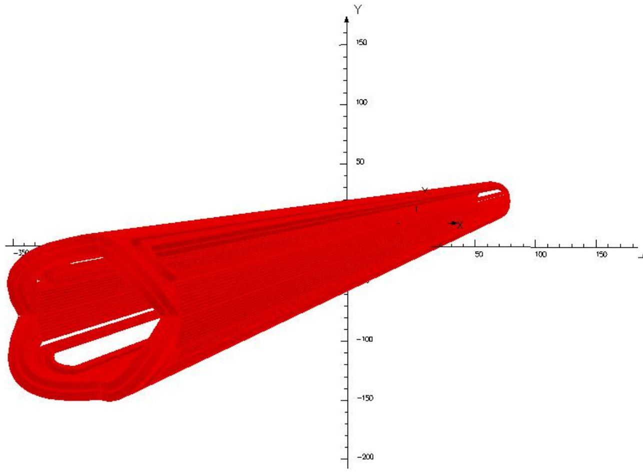
Magnet	Central field gradient (T/m)	Magnetic length (m)	Width of Beam stay clear (mm)	Min. distance between beams centre (mm)
QF1	110	1.48	27.0	146.20

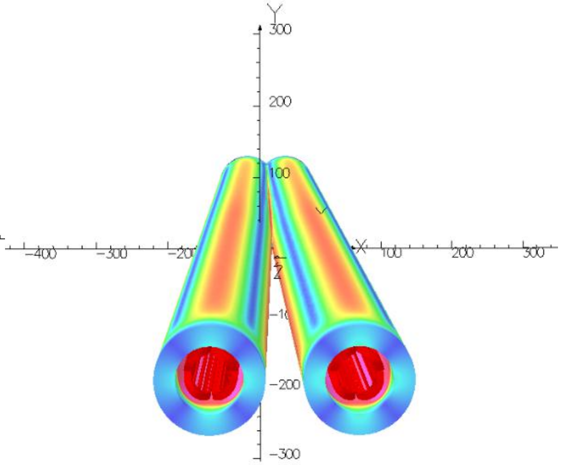
Integral field harmonics with shield coils （$\times 10^{-4}$）

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

SC Magnet Prototype

3D model and field simulation of QD0





Specifications on superconductor strand and cable:

✓**Strand:**

NbTi/Cu, 0.5mm in diameter,

Cu/Sc=1.3, Filament diameter < 8μm,

@4.2K, Ic≥340A@3T， Ic≥280A@4T， Ic≥230A@5T.

✓**Rutherford Cable:**

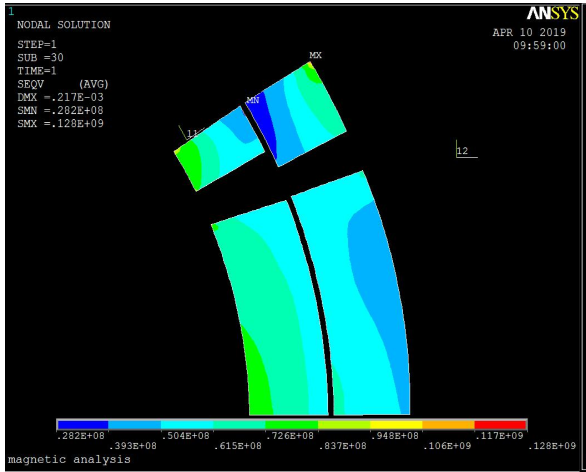
Width: 3mm, mid thickness: 0.93 mm,

keystone angle: 1.9 deg, No of stands: 12.

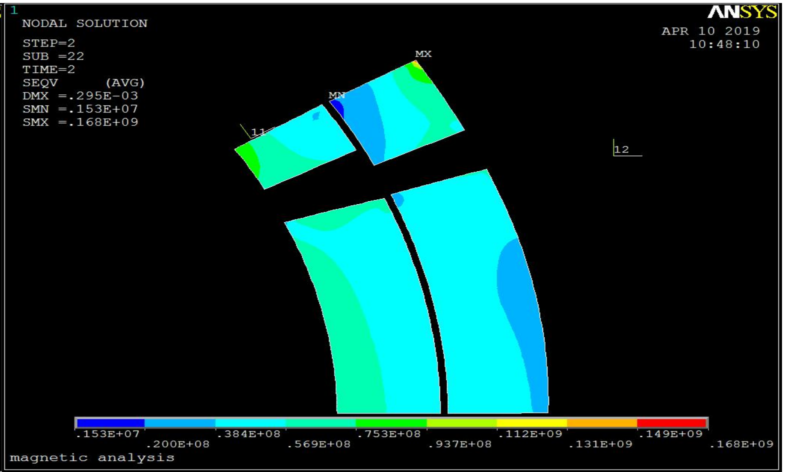
Ordered: NbTi/Cu Strand, Rutherford Cable.

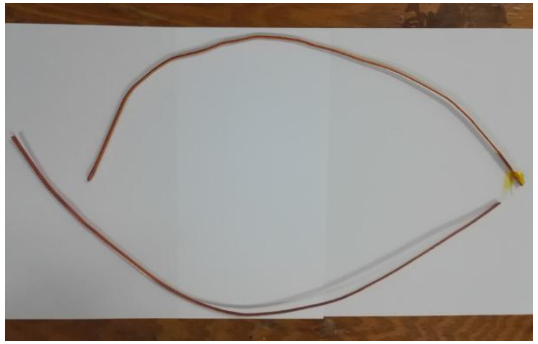
Mechanical and stress analysis of QD0 are in progress

Stress after assembled

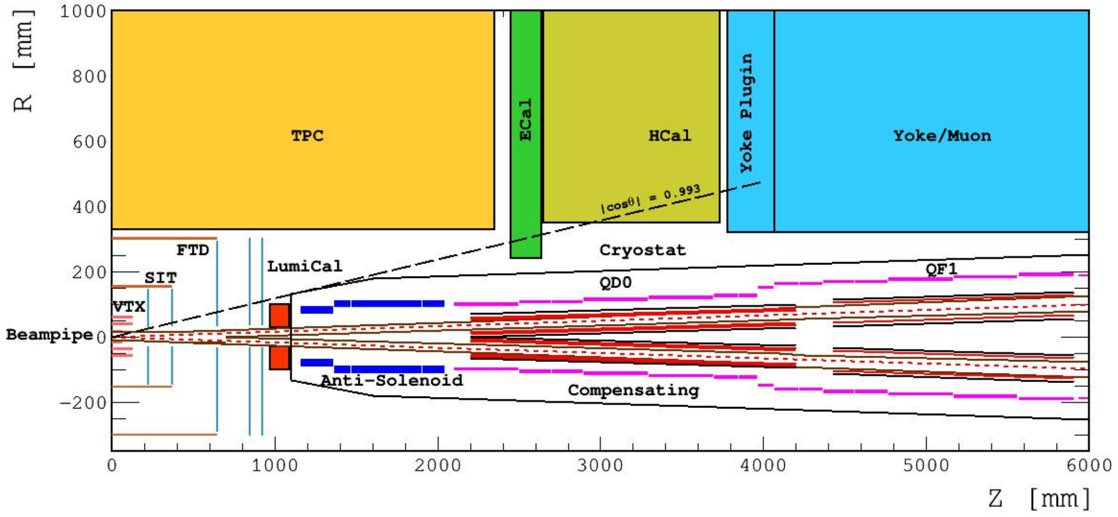


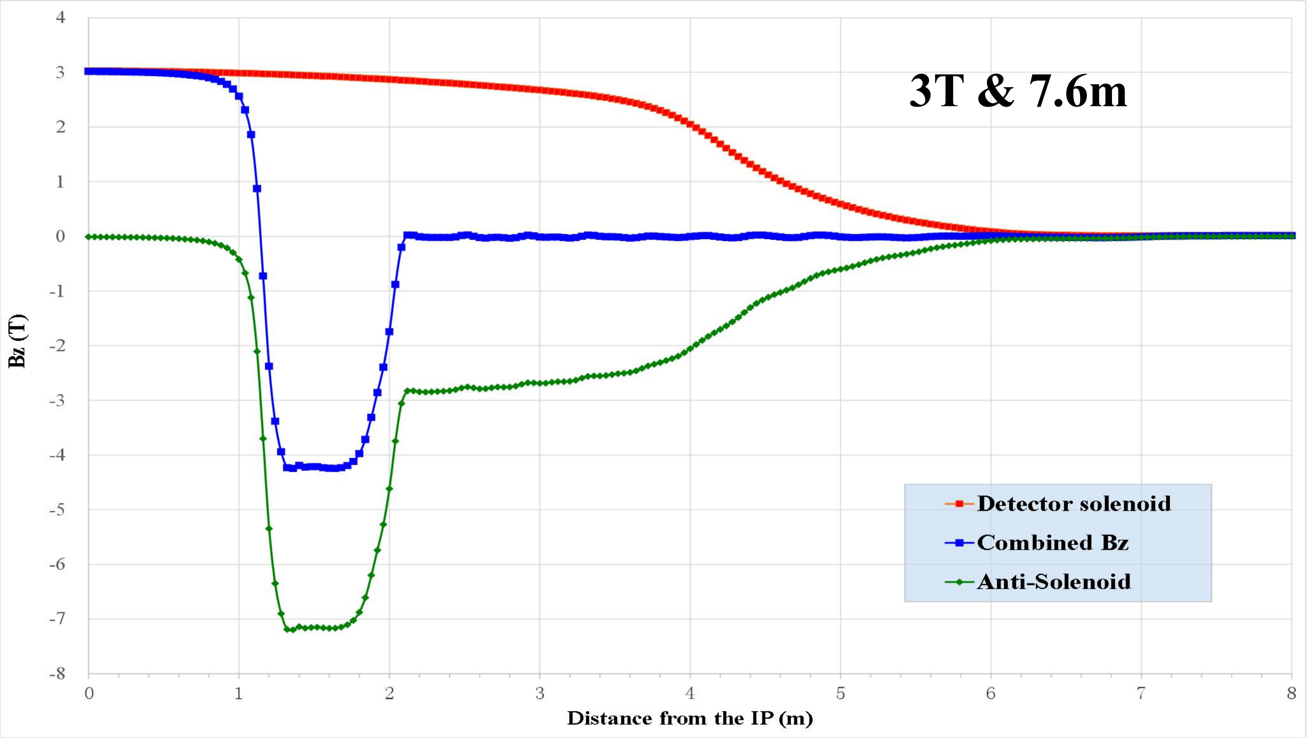
Stress after cool down to 4.2K





Solenoid Compensation



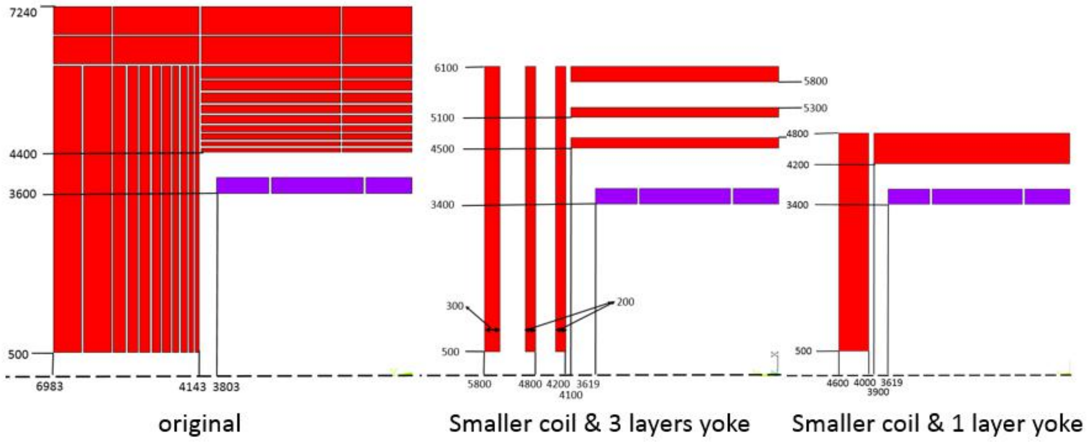


Specification of Anti-Solenoid

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		

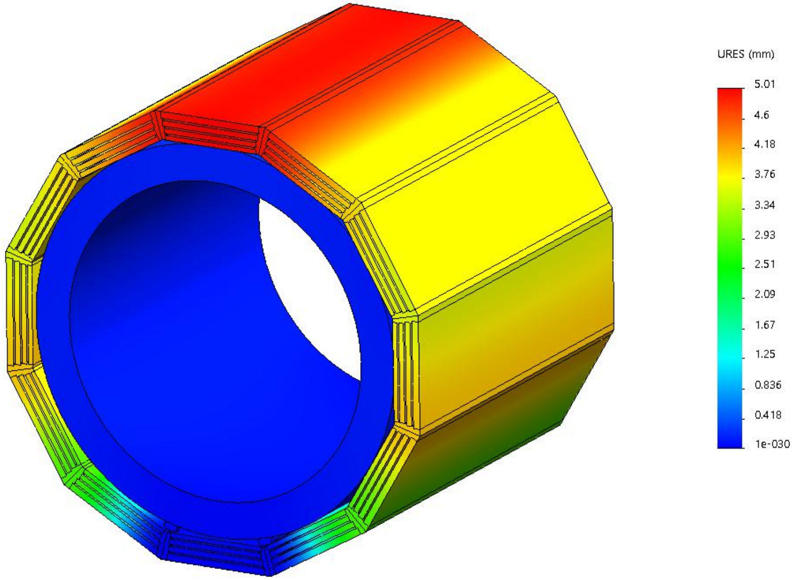
- **$\int B_z ds$ within 0~2.12m. Bz < 300Gauss away from 2.12m**
- The skew quadrupole coils are designed to make fine tuning of Bz over the QF&QD region instead of the mechanical rotation.

Detector Magnet Yoke Wieght Optimization

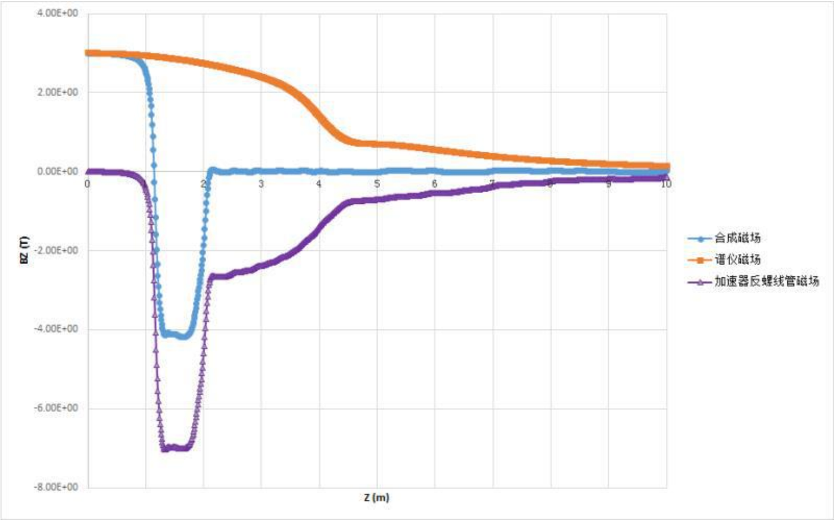


Shape and size comparison: purple part is the coil, red part is the yoke.

	CEPC original	CEPC 3 layers yoke	Smaller coil & 1 layer yoke
Central field (T)	3	3	3
Diameter of coil (mm)	7200	7200	6800
Length of coil (mm)	7606	7606	7238
Barrel yoke inner diameter (mm)	8800	9000	8400
Barrel yoke outer diameter (mm)	14480	12200	9600
Total length of yoke (mm)	13966	11600	9200
Weight of barrel yoke (t)	6122	1608	1125
Weight of each end cap (t)	3419	678	405
Total weight of yoke (t)	12573	2874.5	**1935**

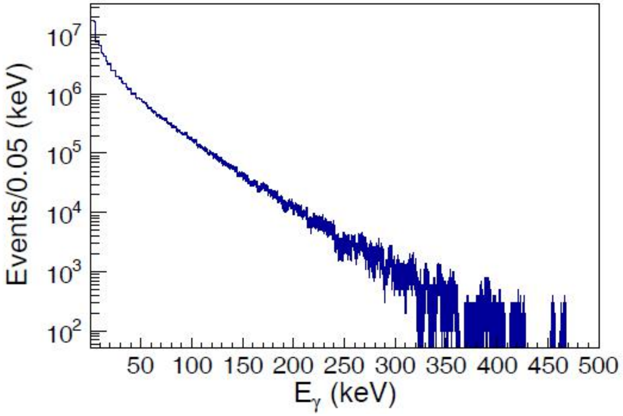


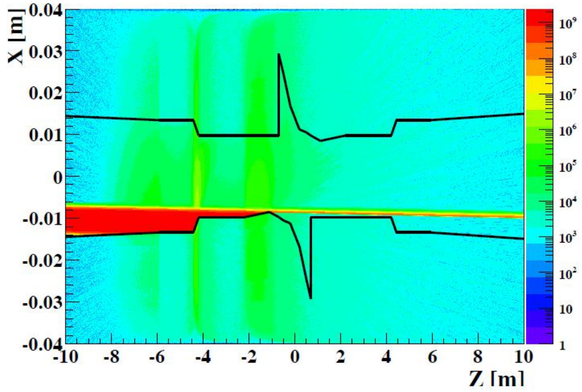
- The original design of detector magnet has a very thick yoke. Reduces the thickness and total weight by 70% and 85% w.r.t the original design.
- Benefits: weight reduced to ¼, cost reduced a lot.
- End cap edge reduced to 4.6m from IP, supporting system design easier.

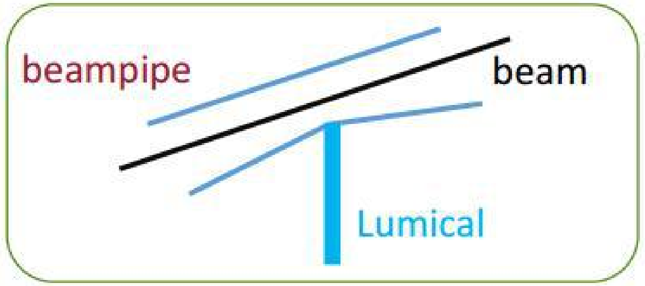


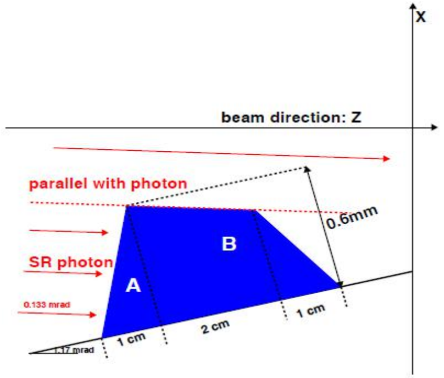
Combined field distribution of anti-solenoid and detector solenoid magnet meets the design requirements.

Synchrotron Radiation

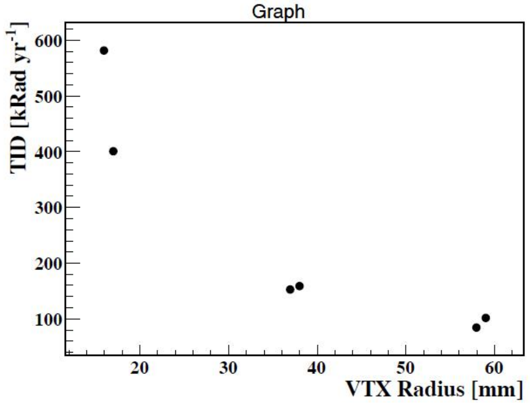


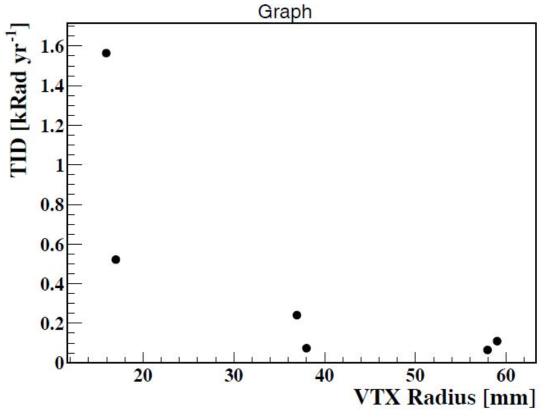


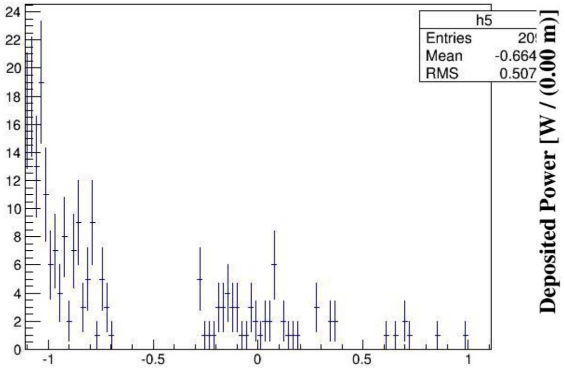


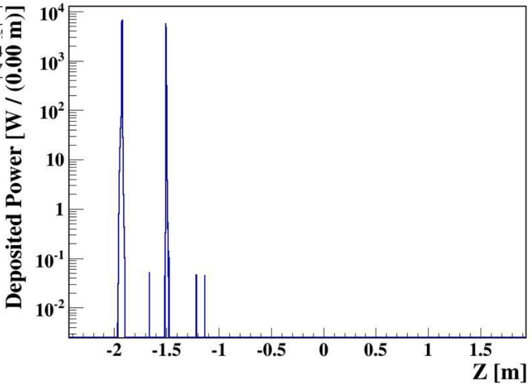


- ✓ Lumical inner radius restrict and three mask position (4.2m, 1.93m, 1.51m), SR photons in ±1.11m are limited. SR power at mask~large.
- ✓ SR from FD and reflection part from mask in ±1.11m region，~mW power.
- ✓ SR from last bend upstream hit beam pipe: QF1~3.1W, L(QF1~QD0)~36.1W, QD0~2.8W, L(lumical~QD0)~28W. Water cooling structure needed.





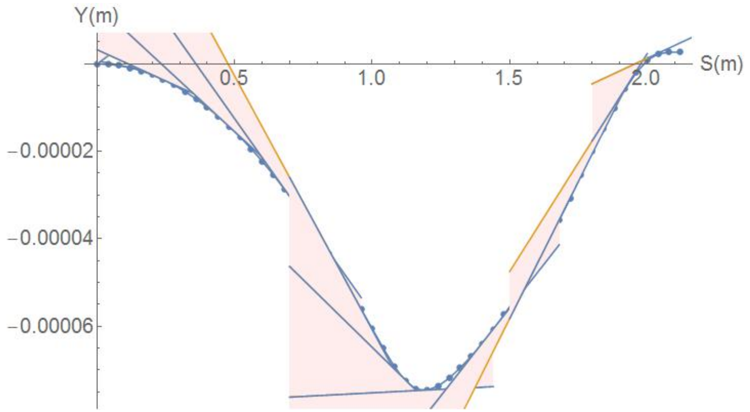




- ➢ 8.6X10^4±293 photons scattering from the Cu beampipe and hit the central beampipe, 7.8X10^4± 279 of them can penetrate the beampipe and hit the detector per beam bunch.
- ➢ The maxinum TID in *cm^{-1}* is about 2 MRad/year.
- ➢ With introducing three masks inside beampipe at Z=-1.42, -1.93 and -1.51 m and made by Au, the number of photons hit and penetrate central beampipe decreased to 233± and 111±2 per beam bunch, respectively. The TID for each layer is decreased by more than two order of magnitudes.

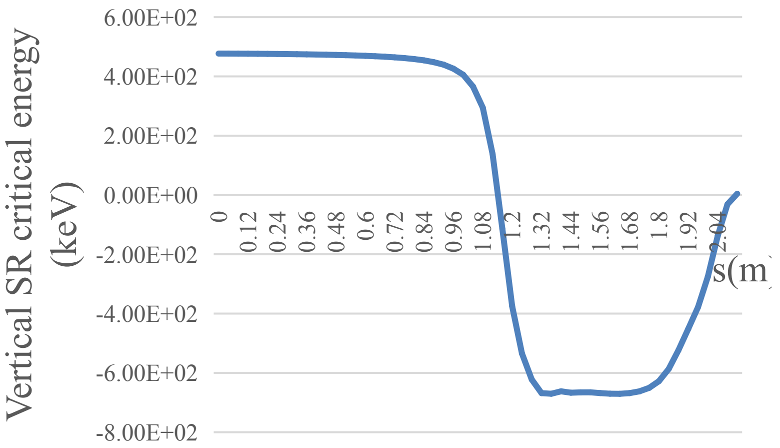
SR from Solenoid Combined Field

- 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.



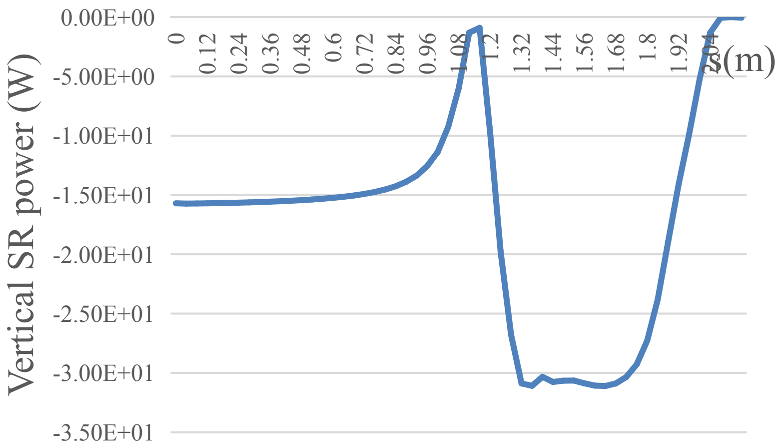
- SR sector is focused in a very narrow angle from -116urad to 131urad
- SR will not hit Berryllium pipe, and not background to detector.
- SR will hit the beam pipe ~213.5m downstream from IP
- Water cooling is needed.

Vertical SR critical energy distribution

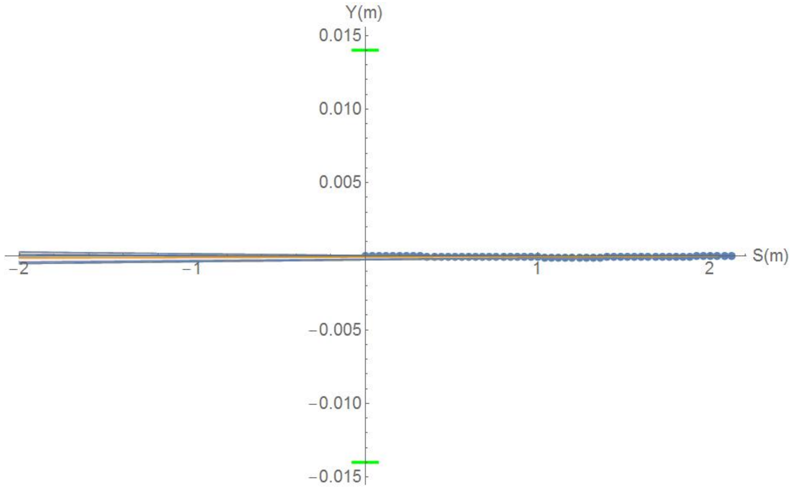


Maximum: 670keV

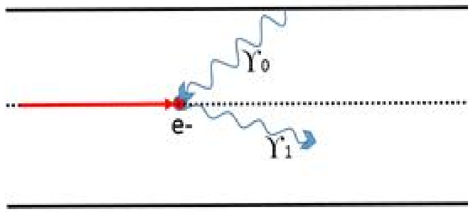
Vertical SR power distribution



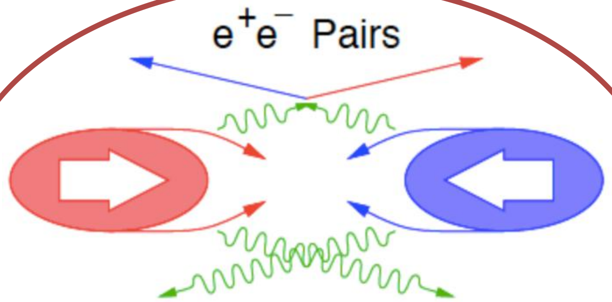
Maximum: 31W



Beam Loss Backgrounds at CEPC



Beam-Thermal photon scattering



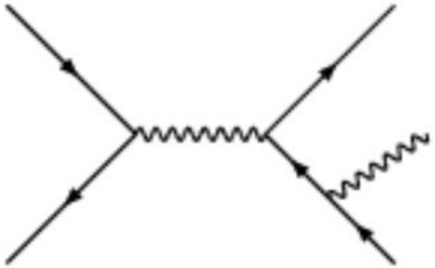
Beamstrahlung

IP1

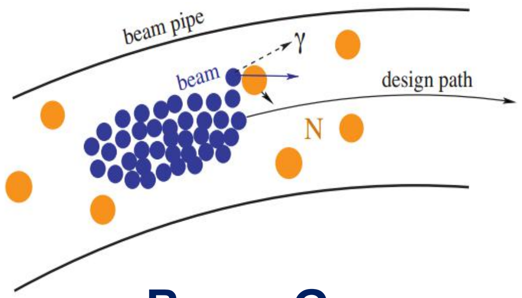
242 bunches
Revolution frequency: **2997**Hz
1.5×10^{11} particles/Bunch
L: $2.93 \times 10^{34} cm^{-2} s^{-1}$

IP3

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



Radiative Bhabha scattering

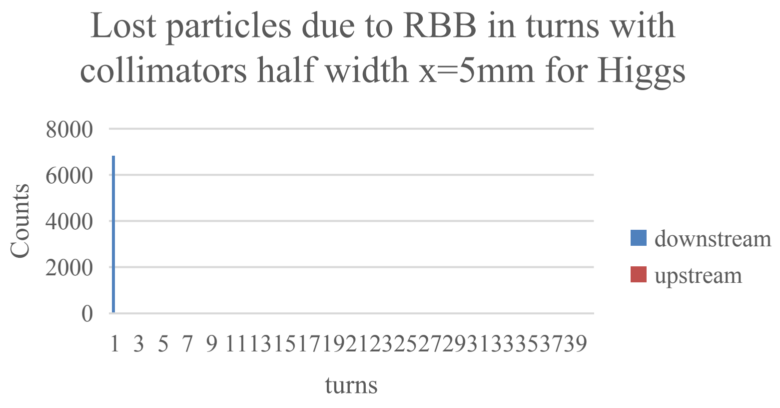


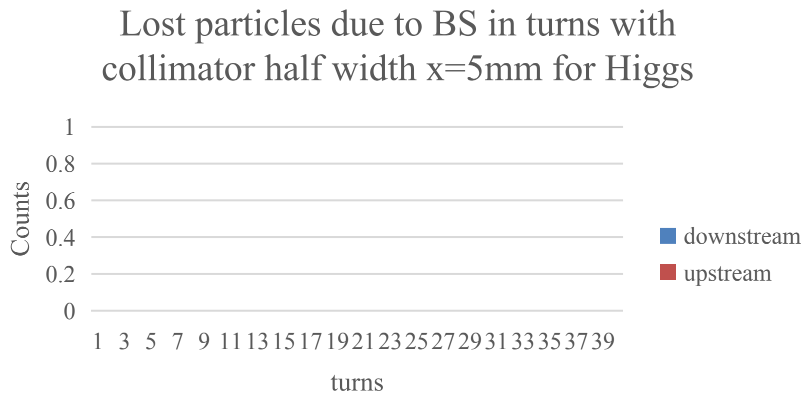
Beam-Gas Scattering

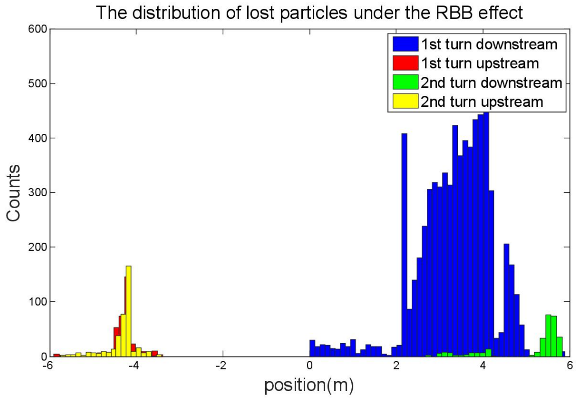
CEPC Beam Lifetime

	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	

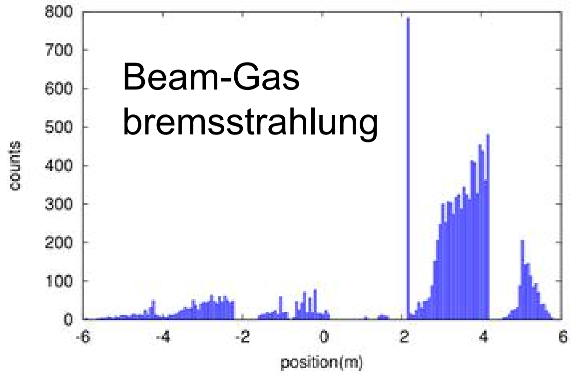
Beam Loss Background

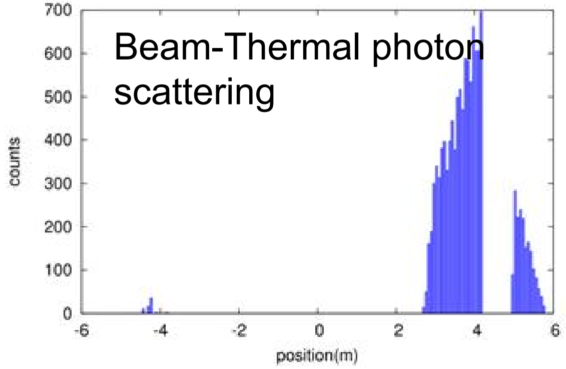






- Beam loss reduced to very low level with collimators for both RBB and BS.
- Beam loss in the downstream of the IP~large in the 1st turn, radiation damage and background acceptable.
- SC magnet quench needs to be fixed.
- Simulation without beam-beam, fluctuation and errors, will be added in next plan.
- Injection background not considered, will be added in next plan.

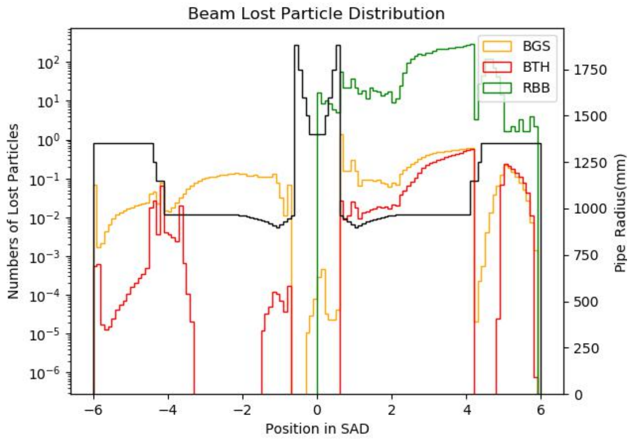




- Beam loss upstream reduced to very low level with collimators for BT.
- Beam loss upstream in BG could be optimized for next.

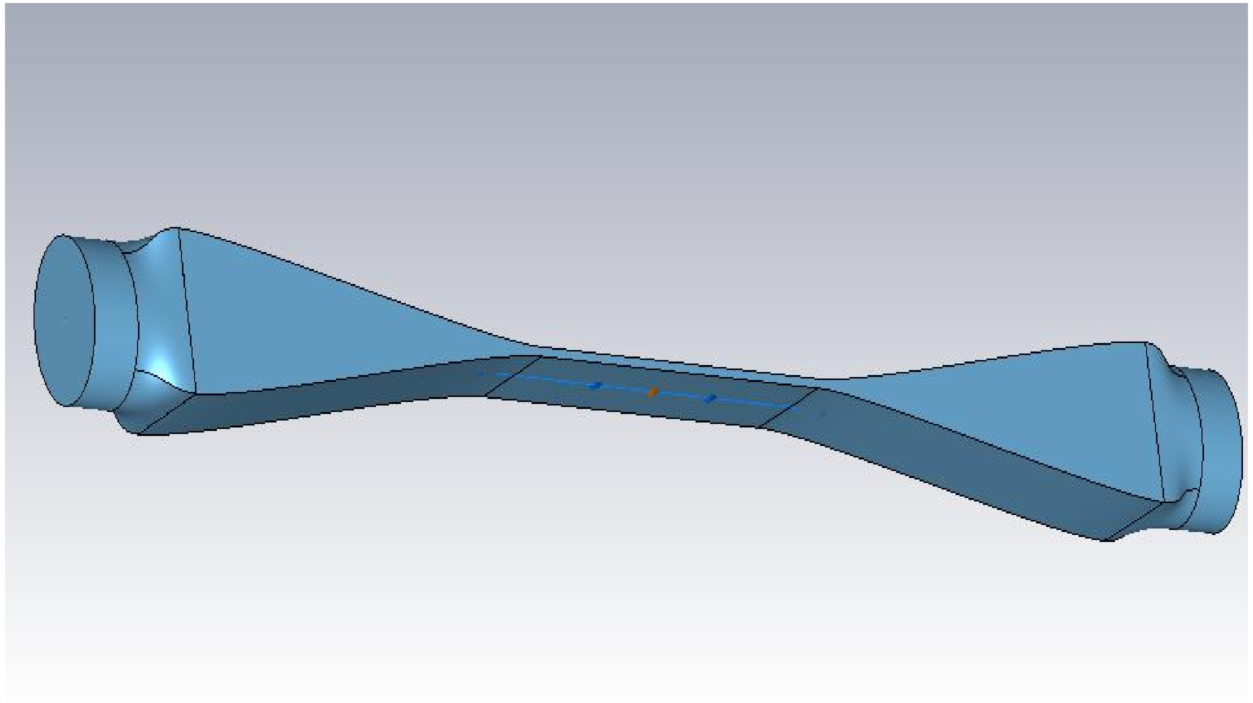
Beam Loss Background in Detector

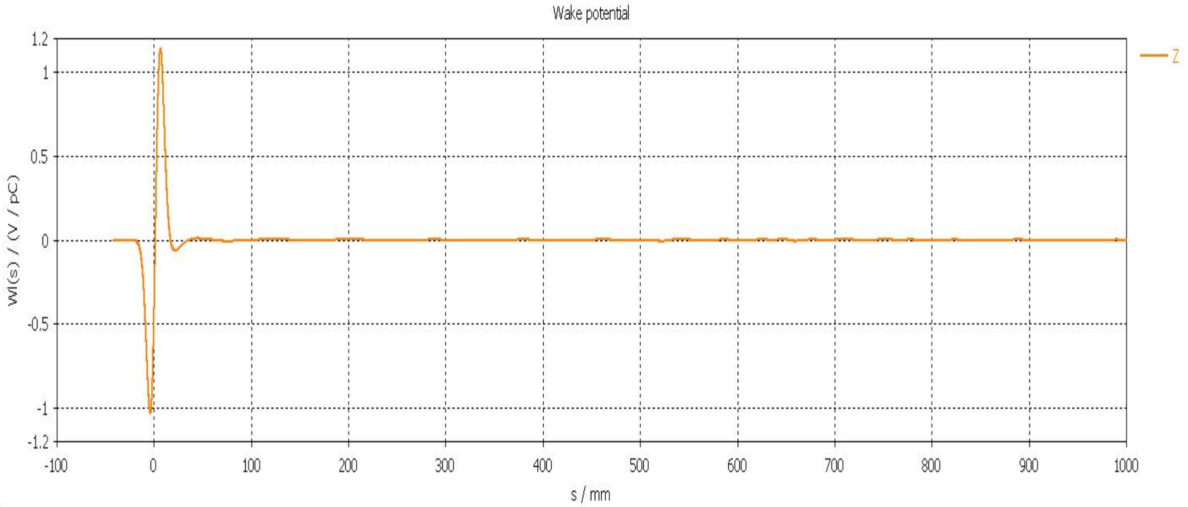
- Concluded on 08/29/2019, **Preliminary** results, with a safety factor of 10.
- Including Radiative Bhabha, Beam-Gas scattering, Beam Thermal Photon scattering and Beamsstrahlung.
- Normalized to per bunch(one beam).

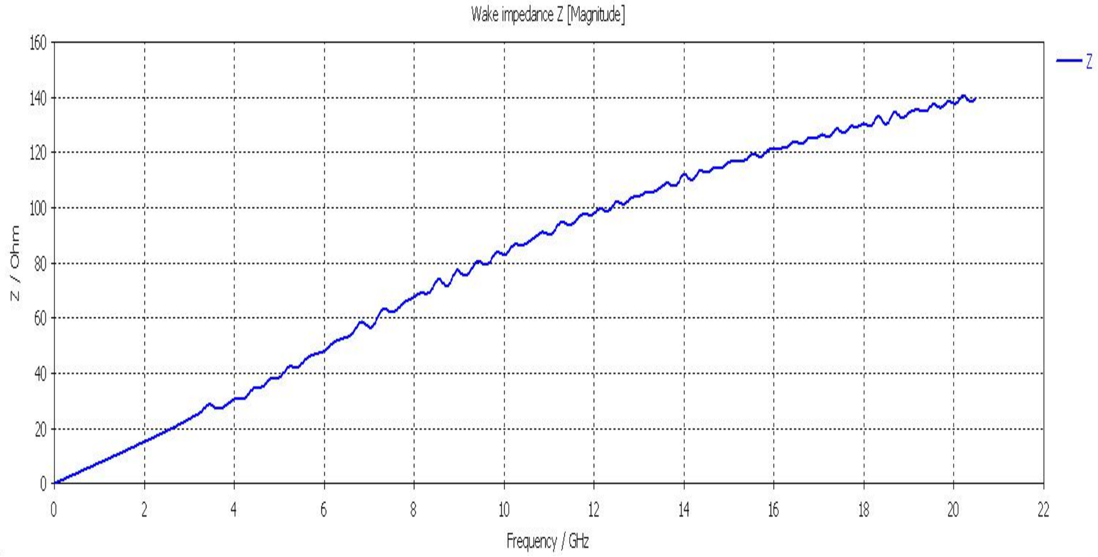


Background Type	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)	1 MeV equivalent neutron fluence ($n_{eq} \cdot cm^{-2} \cdot yr^{-1}$)
Pair production(Guinea-pig)	2.26	591.14	1.11e+12
Pair production(Cain)	1.18	334.34	6.10e+11
Radiative Bhabha Scattering	0.16	197.99	3.55e+11
Beam Gas Scattering	63.04	73515.1	1.69e+14
Beam Thermal Photon Scattering	10.30	9615.1	2.05e+13

Collimator Impedance

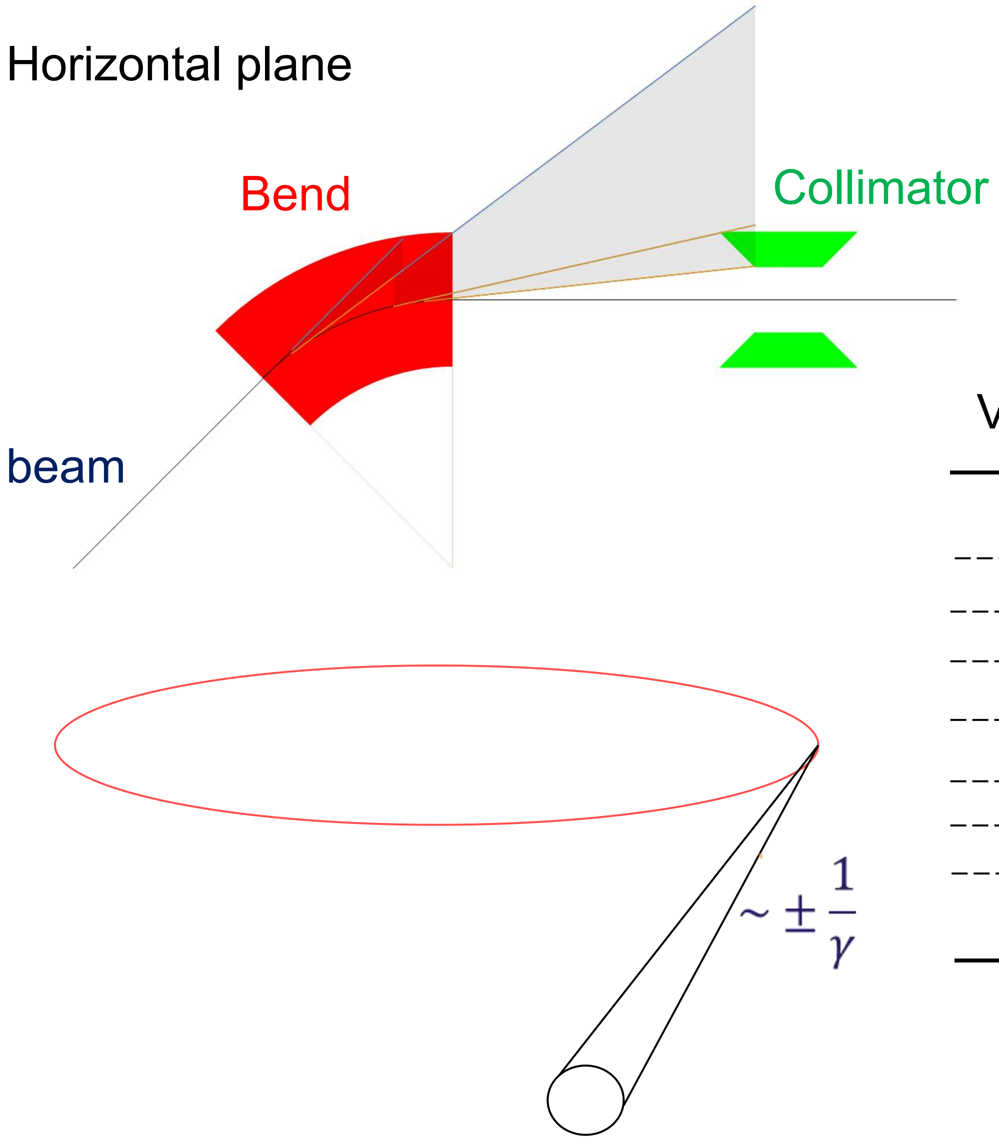


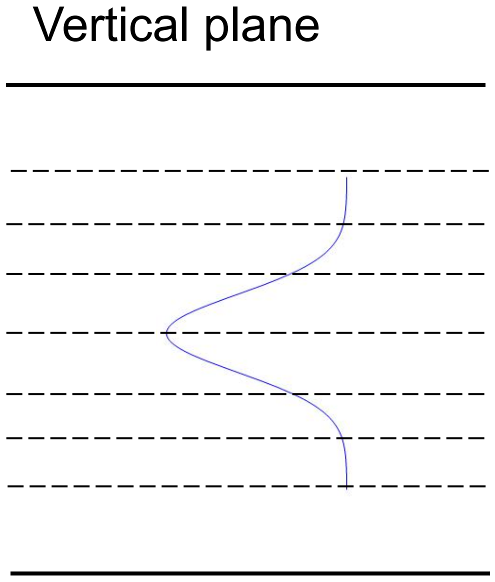




Wake Integration type : Indirect Interfaces
Simulated wake length : 1000 mm
Wake shift x : 0 mm
Wake shift y : 0 mm
Wake-Loss-Factor : 1.403765e-001 V/pC
Entry interface at z-coordinate: -3.851471e+002 mm (grid-index: 102)
Exit interface at z-coordinate : 3.851471e+002 mm (grid-index: 4681)

Synchrotron Radiation at Collimator

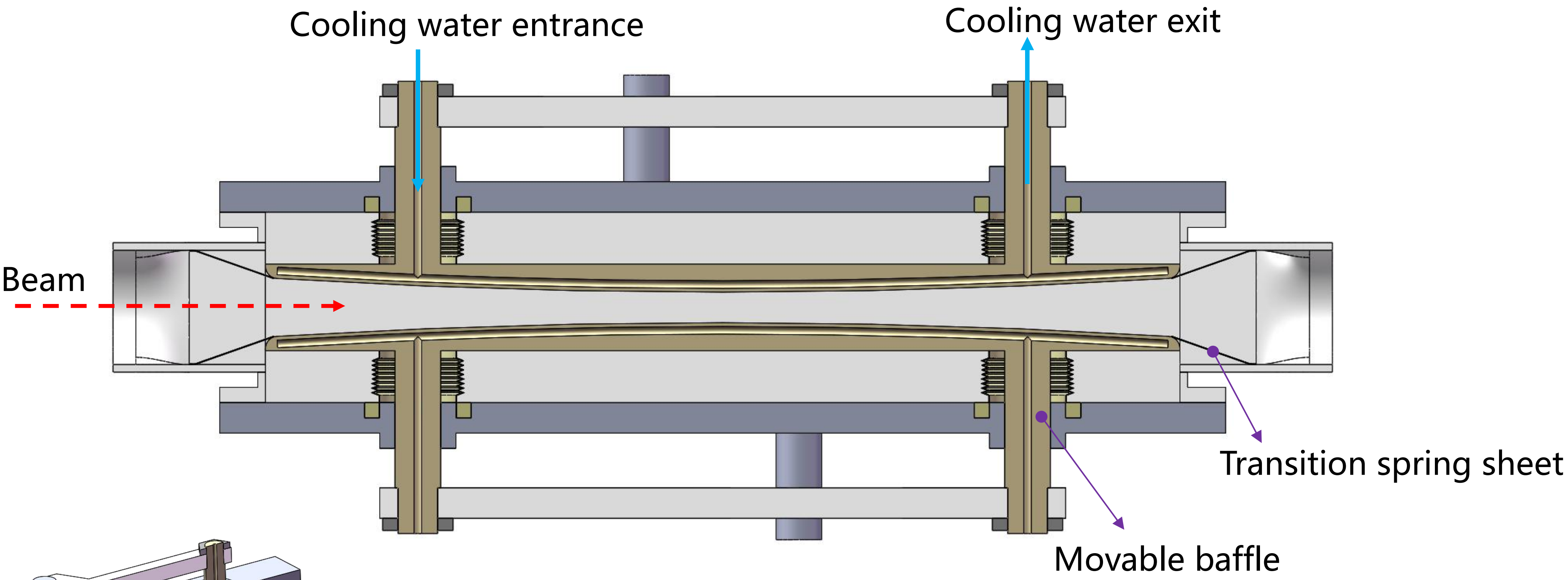


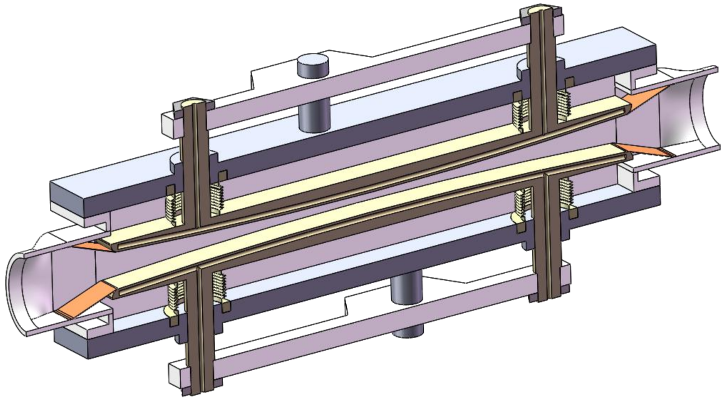


$$\sigma'_y = \sqrt{\sigma'^2_{y\beta} + \sigma^2_\theta}$$

- ✓ 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.

Collimator Design Structure





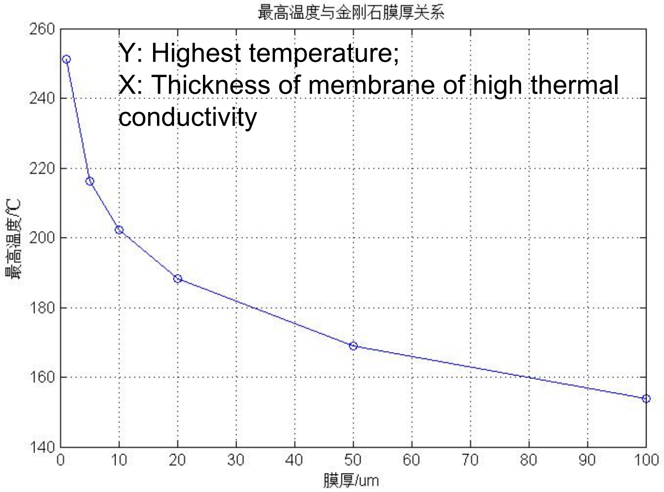
- ✓ Considering the collimation section, the movable baffle can not protrude the step between the vacuum pipe and the collimator section. The vacuum pipe in the collimator section transits from elliptical section to rectangular section.
- ✓ During the moving process of the movable baffle, the spring sheet is always pressed on the baffle to realize the gradual transition of the moving process.
- ✓ Structural design and refinement (including machinery, vacuum, etc.); drive scheme design (drive, control, etc.); material selection (considering physical requirements, heat dissipation, strength, etc.); finite element simulation (thermal-structural).

Collimator Design

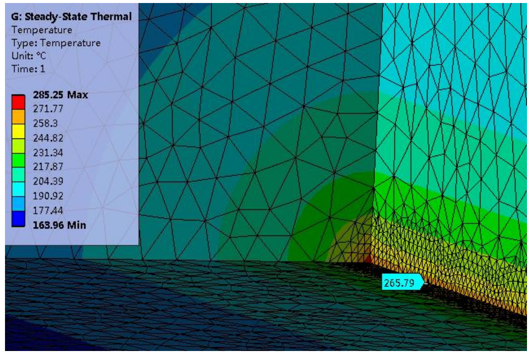
- Difficulties
  - High thermal load. The synchrotron radiation power is 7700W
  - Minimize impedance. Design of RF fingers will be considered in the next step.

Cooling method	Loads	Highest temperature （℃）
Copper & water	Linear load	266
Laminated material & water	Linear load	146
Copper & water	Surface load (Damping of X ray)	141

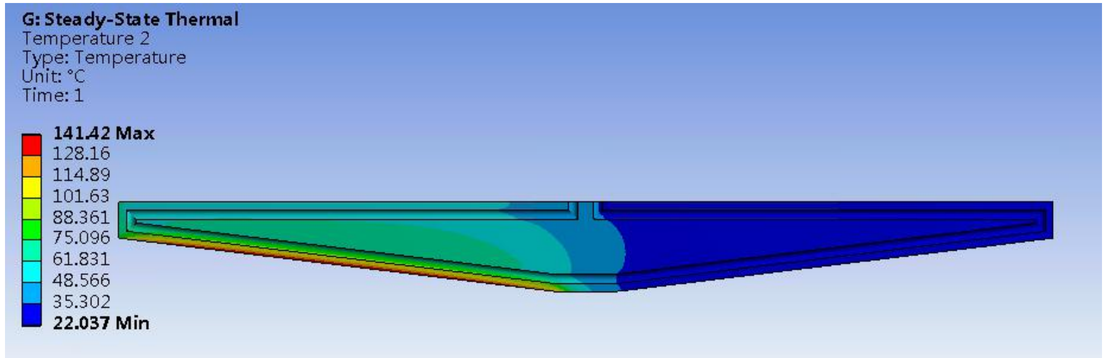
A design is proposed using laminated material with metal and membrane of high thermal conductivity, the photon absorber is also considered.

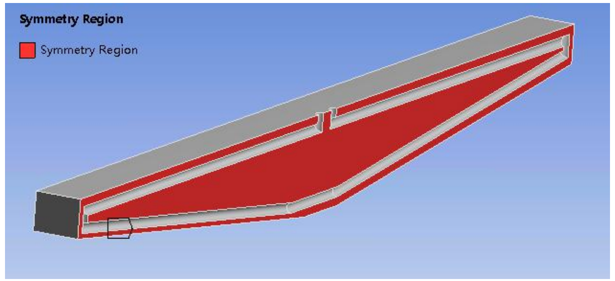


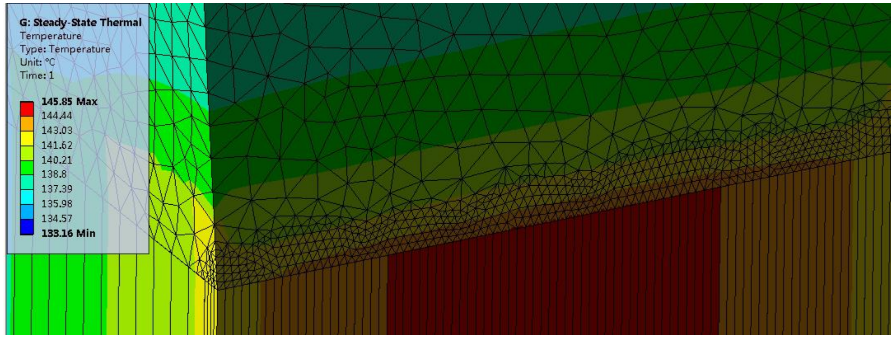
Copper & water, linear load



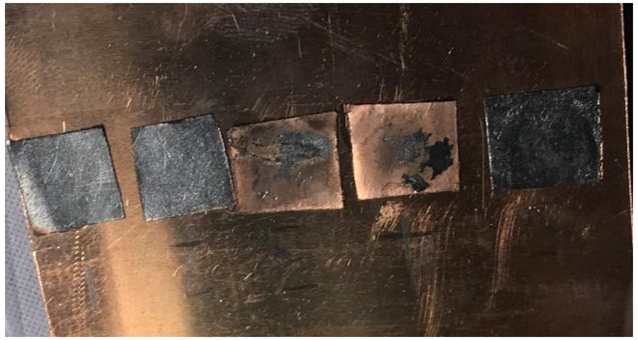
Copper & water, surface load





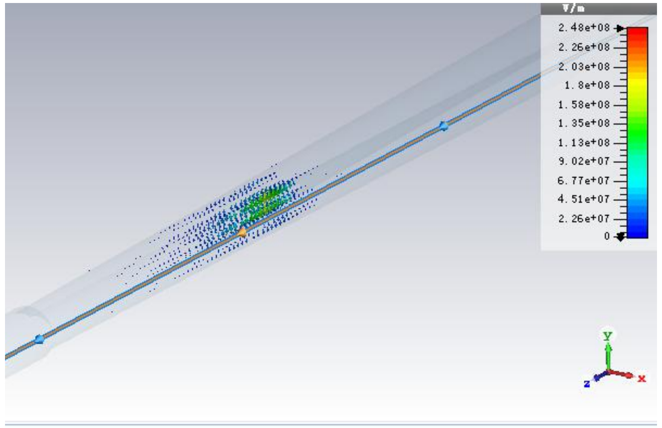


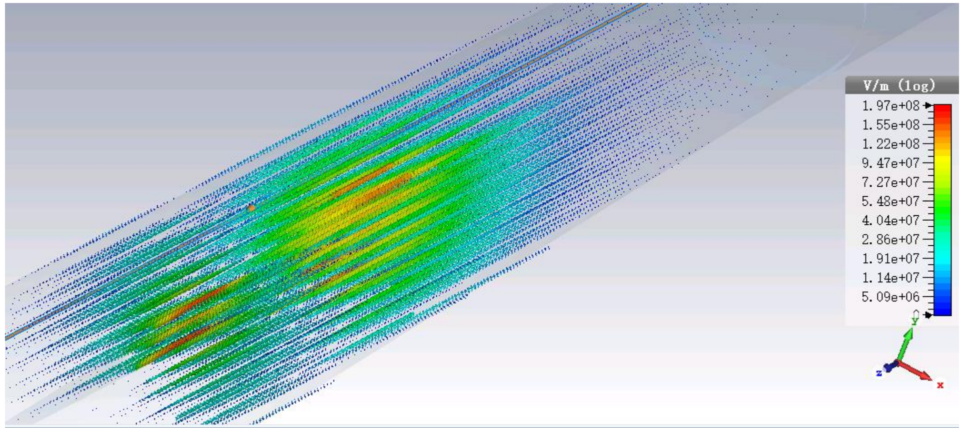
Laminated material & water, linear load



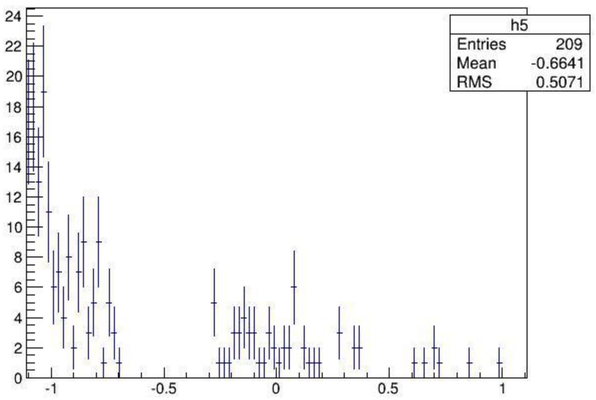
Laminated material with copper and graphene film
(Supported by one NSFC, have no money now)

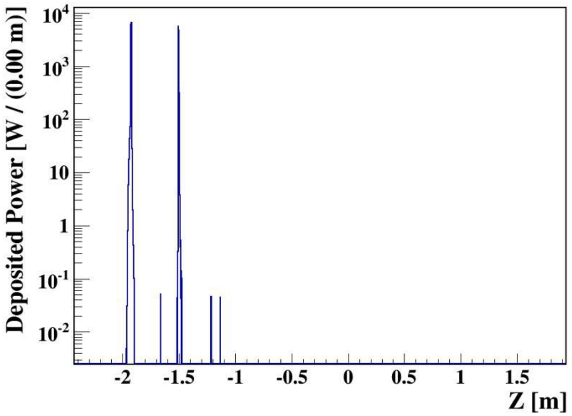
HOM Absorber

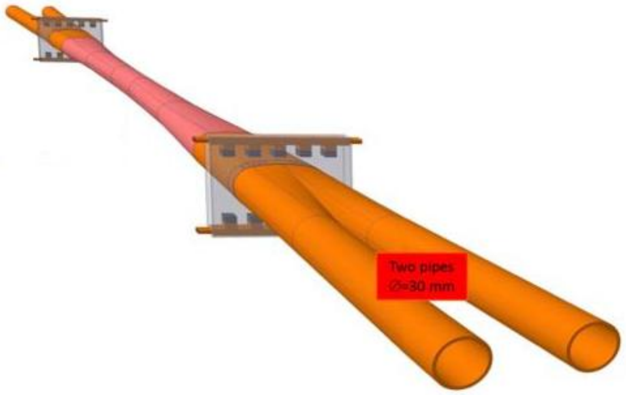




- HOM at crotch point（z~±700mm）
- HOM frenquency 10GHz, close to cut-off frequency (decided by beam pipe aperture).
- HOM power ~3kW.
- This mode is trapped mode.
- HOM absorber is needed，water cooling system considered.



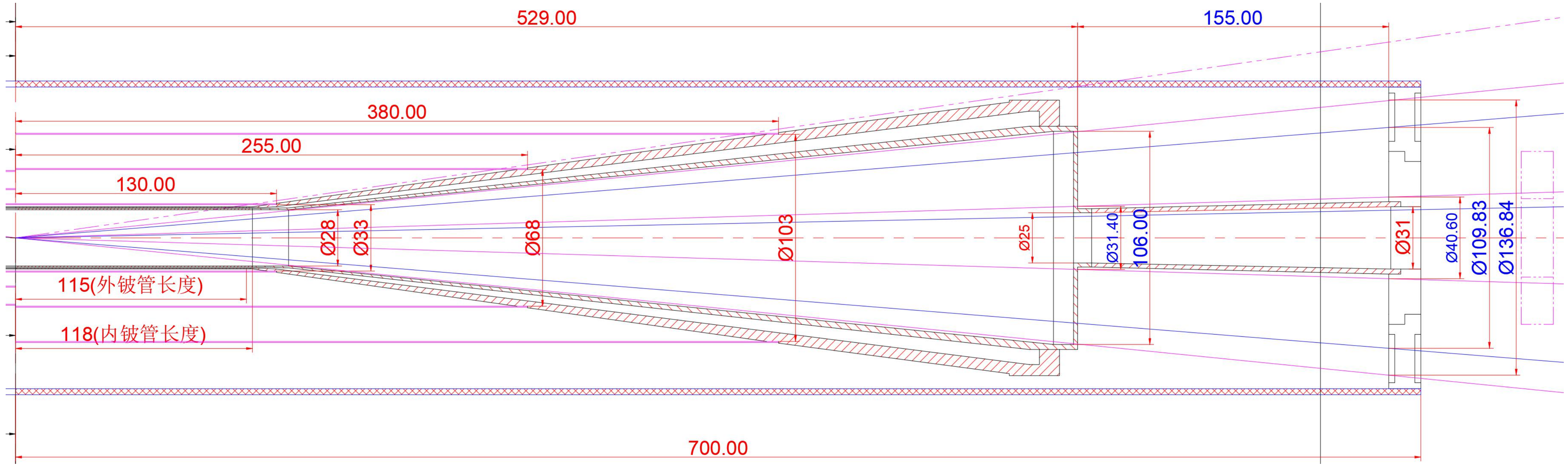




- ✓ Synchrotron radiation from Final doublet magnets and reflection part from mask，~mW power.
- ✓ SR resistance acceptable for HOM absorber

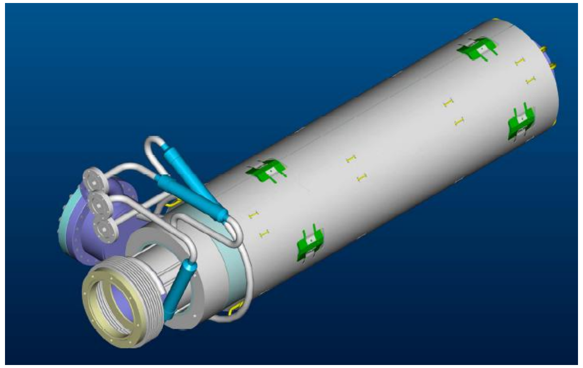
- HOM absorber design refer to FCC, under development
- Distance from IP is around 70cm just before the crotch point, no space conflict with RVC and IP BPM.
- Impedance

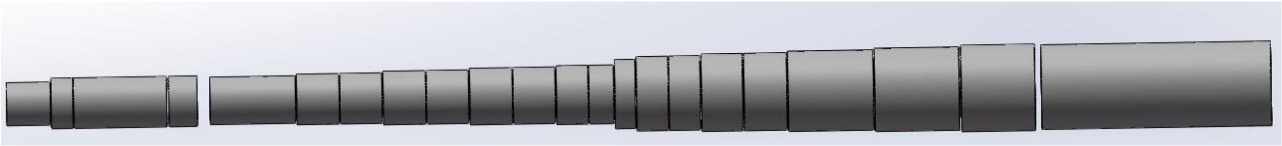
New Design of IR Beam Pipe

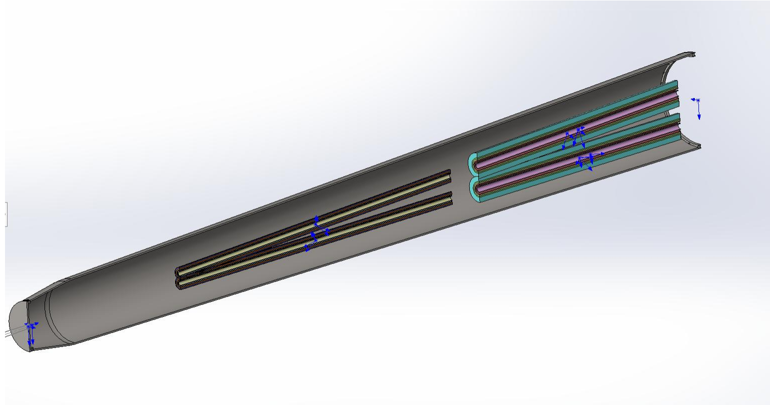


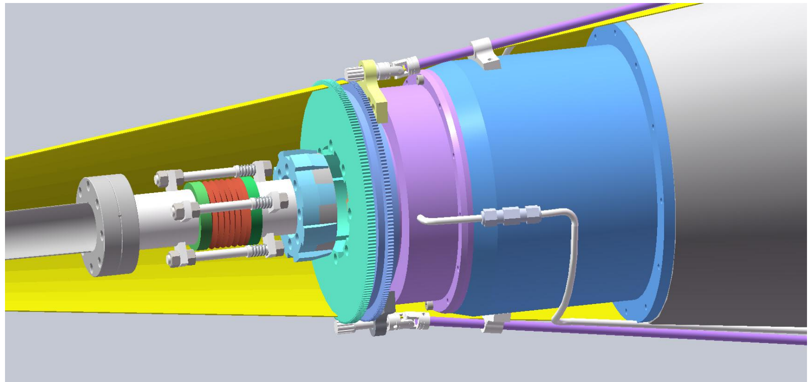
- Move LumiCal closer to the IP and mount it on the detector supporting structure (total weight ~10kg)
- Lumical location between 529 – 684 mm, angle coverage between 30 – 100 mrad (or less to leave space for routing cables)
- Central beryllium beam pipe extended from z=±70 mm to~±130 mm; double layer structure, inner layer thickness 500 um, outer layer thickness 350 um, gap ~350 um filled up with coolant.
- Forward region with shape of opening cone shape with double layers of aluminum, gap filled up with coolant (water)?, ending wall of thin aluminum in front of LumiCal.
- Introduced additional supporting structure for LumiCal and the long beam pipes, *exact design to be decided*
- *easier IR installation, enclosed structure (improved air flow control and thermal management).*

CEPC MDI SC Magnets and Mechanical Study

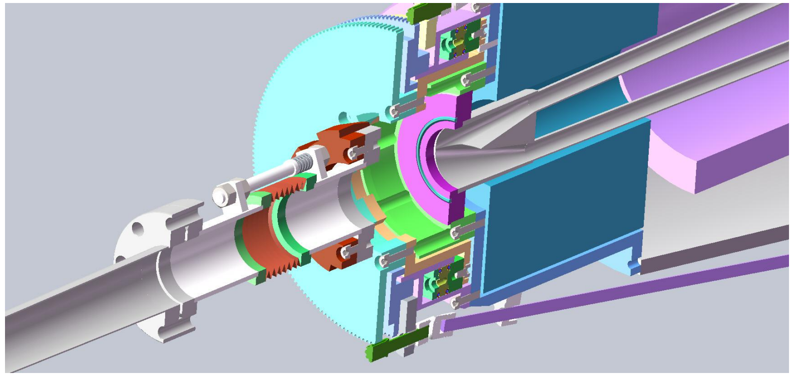


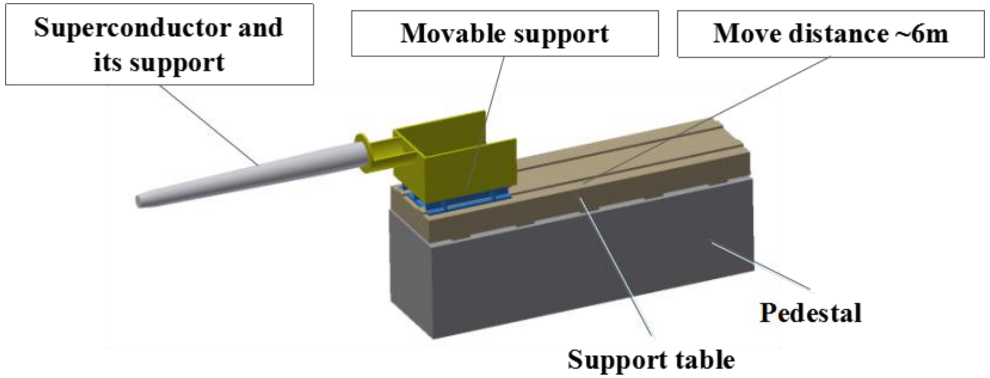






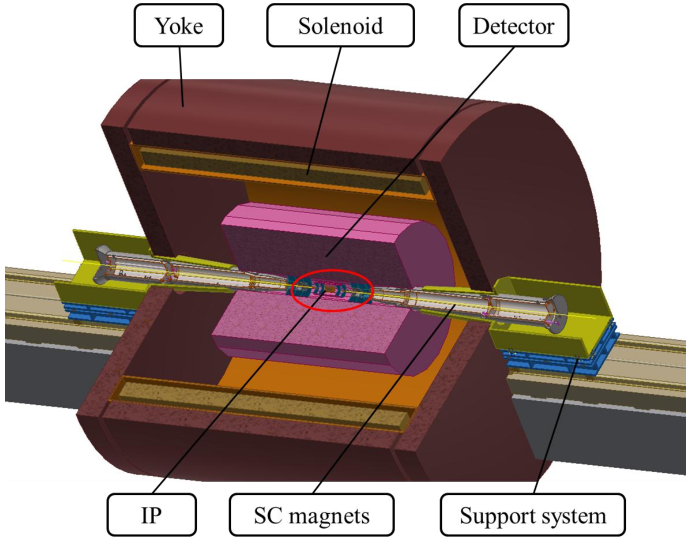
Technical design review has been done (July 23, 2019)

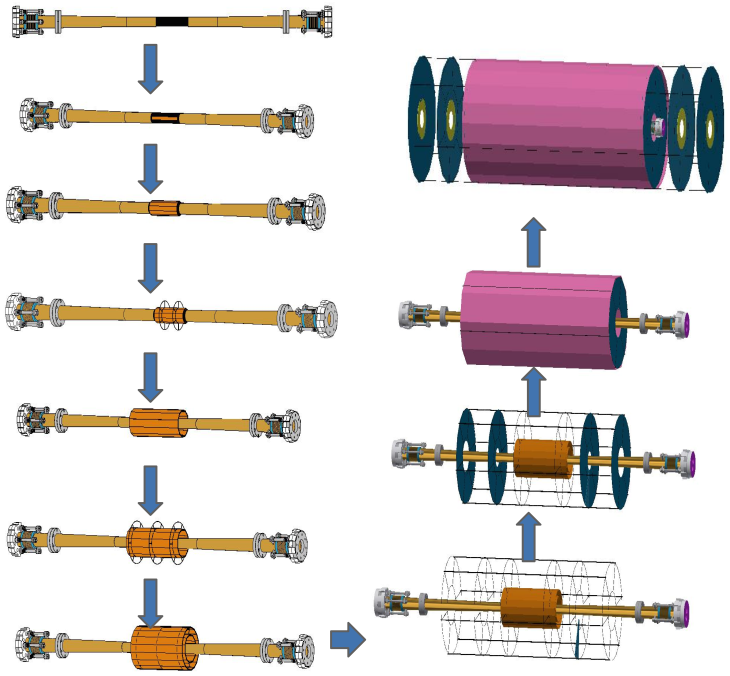




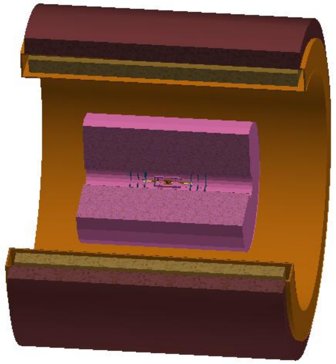
Schematic of support system of superconducting magnets

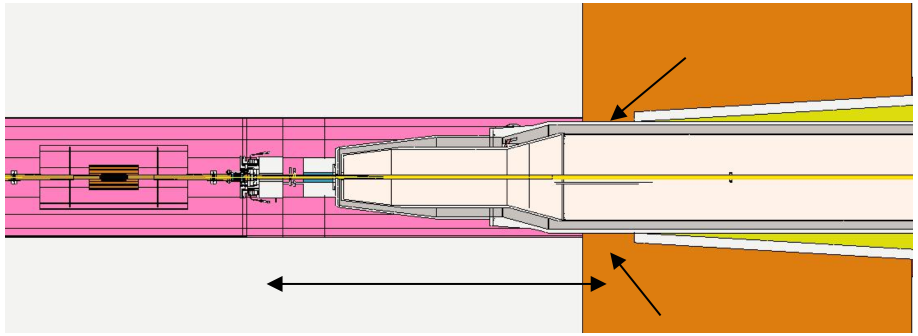
IR Mechanics Assembly-1





- Both sides of IP chamber are fixed to VTX transversally and are free longitudinally.
- The IP chamber, VTX, SIT and FTD can be considered as one assembly.
- The assembly above can be supported by TPC and be aligned transversally.
- Remote vacuum connector can be used.
- The high precision part of Lumical is with the detector and the main body is with the accelerator.

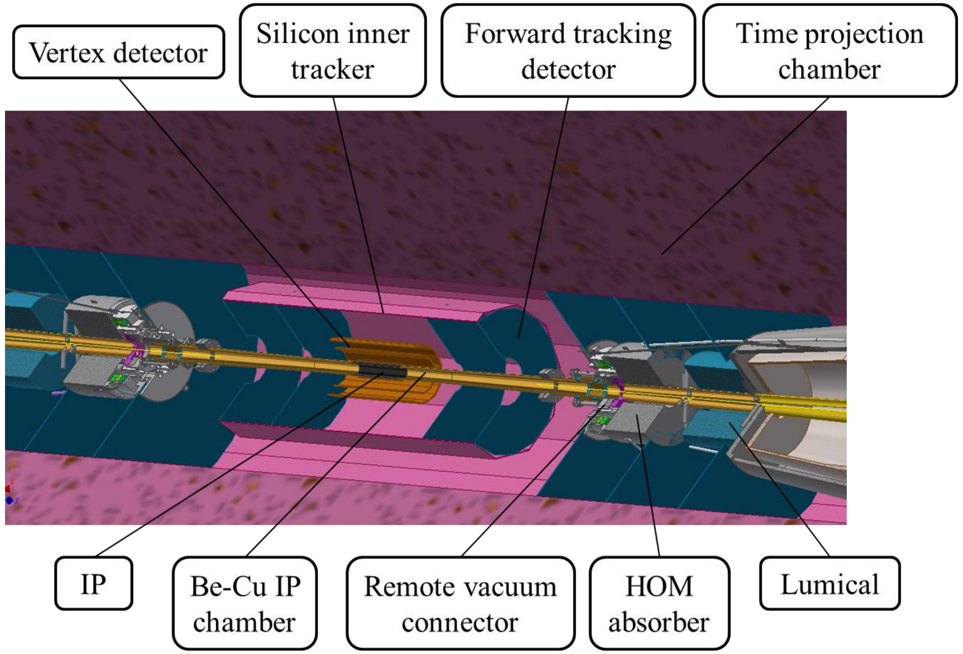


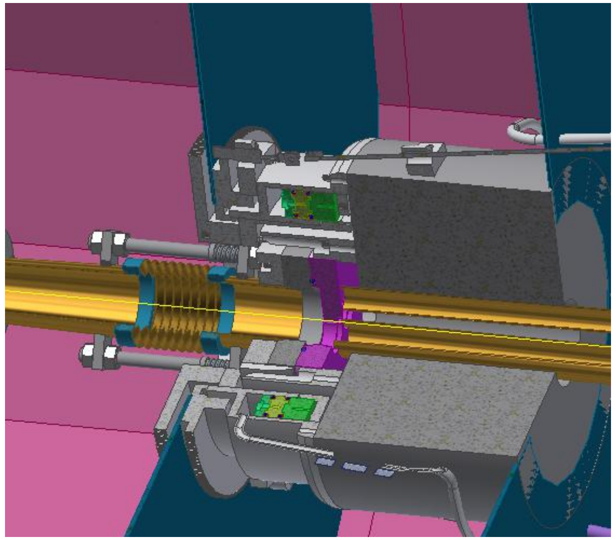


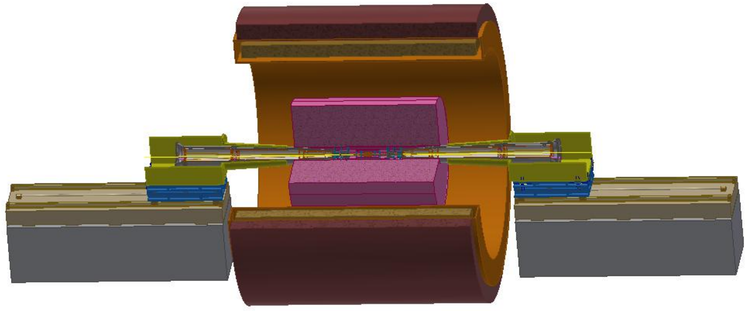
Little transversally space & long longitudinally distance. It is impossible to connect flanges by hands.

Technical design review has been done (July 23, 2019)

IR Mechanics Assembly-2



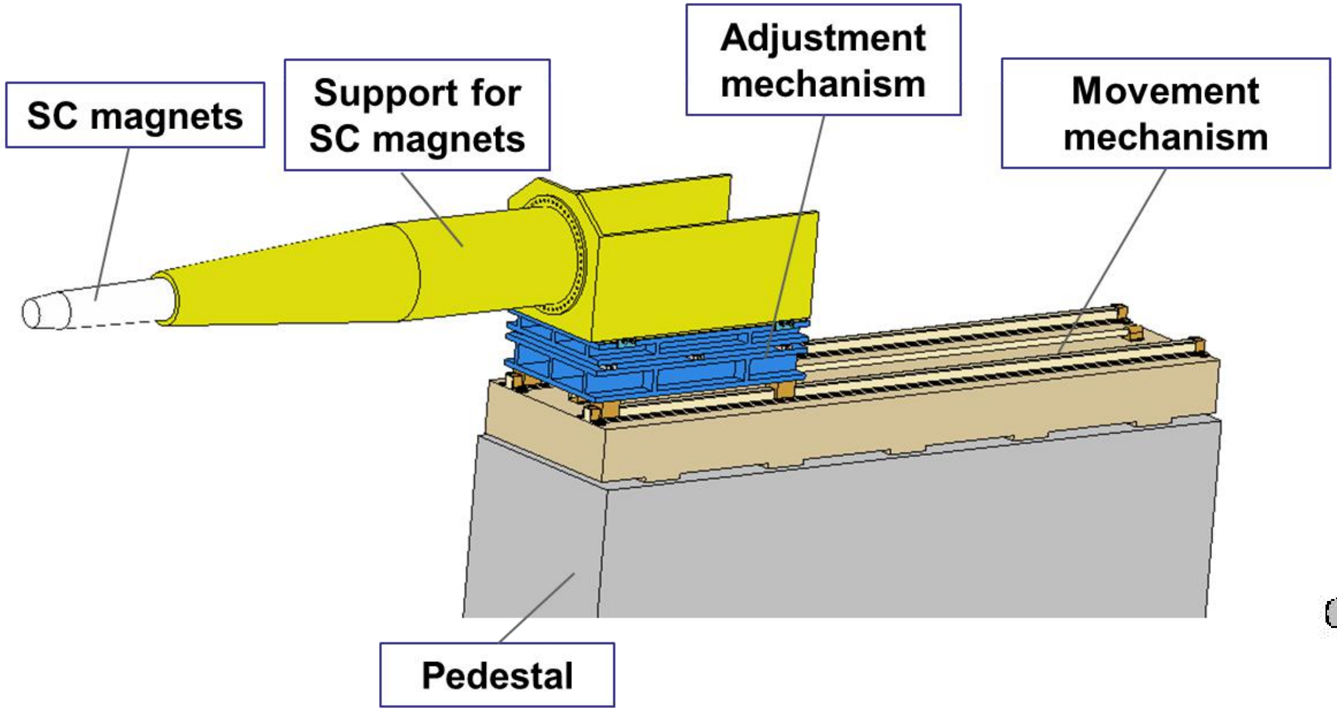




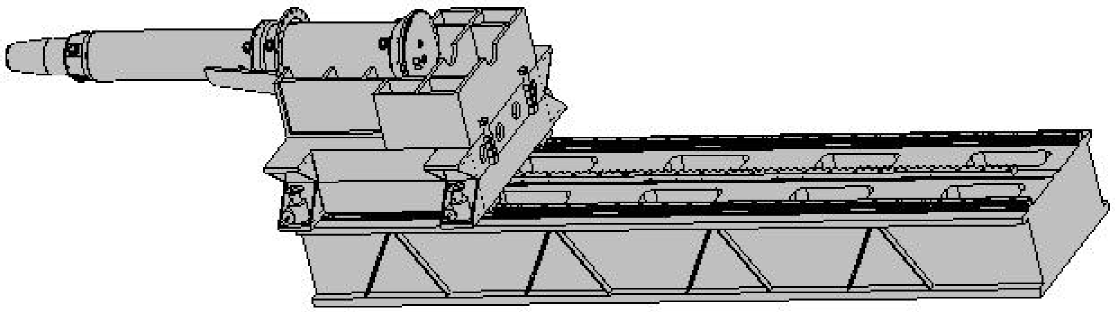
- Move the SC magnet to working location. Connect the flanges using RVC, do the alignment.
- Requirements: accuracy: ≤(30 μm), leak rate ≤2e-10 Torr.L/s
- Alternative design for remote vacuum connection is also under consideration.
- Finish the connection and alignment for both sides, install the yoke walls.
- We need holes through the yoke walls for alignment, or to open them.
- We are trying our best to reach the accuracy requirement, but no clear solution yet.

SC Magnet Supporting System

- Preliminary design， alignment adjust（manual operation、Push-pull screw+wedge block）、transmission scheme（electric, gear, rack and guideway）
- Distance from front of supported equipment to detector 3757~6140mm.



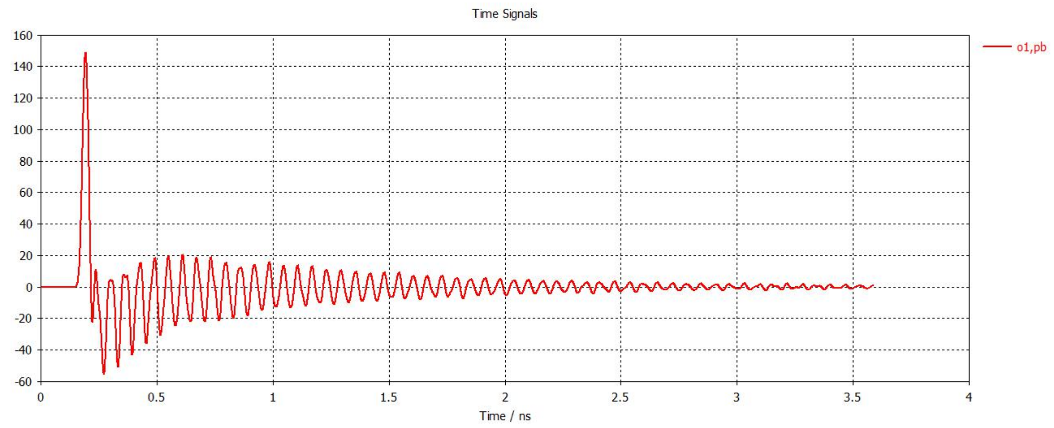
- Methods to improve the accuracy in consideration
  - Adjustment mechanism: wedge jacks in three directions.
  - Movement mechanism: high precision tracks & rack, in Z direction.
  - Optimization will be done to increase the rigidity in limited space.
  - Sensors will be used for deformation monitoring.
  - Special structure and alignment method will be used for high accuracy requirement, but it’s not clear now.



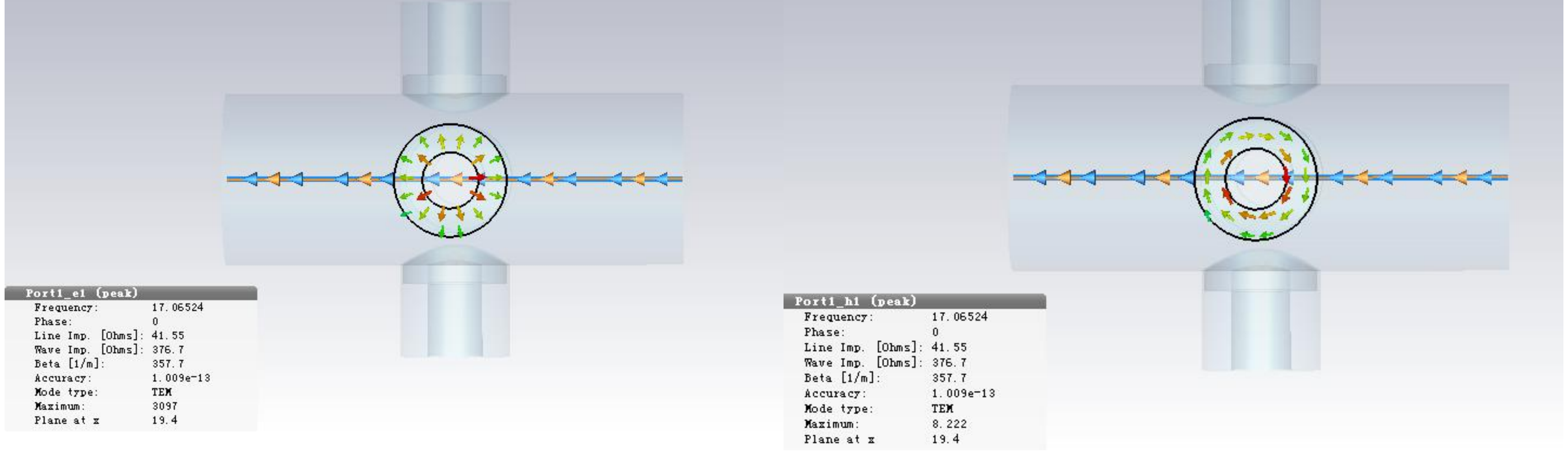
IP BPM-1

- Considering response time and calibration difficulty, two 4 button electrodes BPM at each side of CEPC IR is adopted.
- 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

Electrodes signal(bunch length 2.68mm)



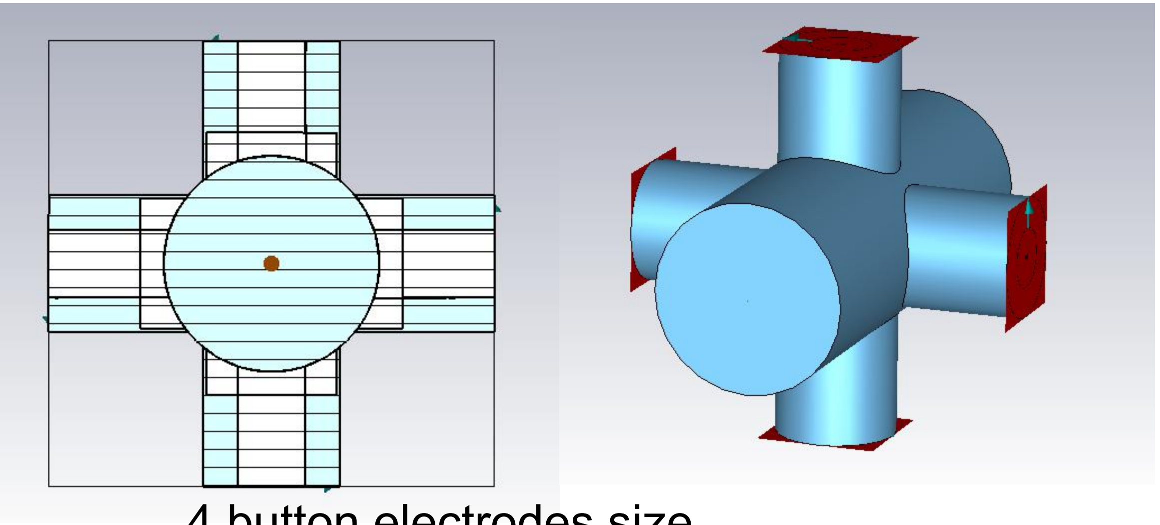
Electromagnetic field at electrodes



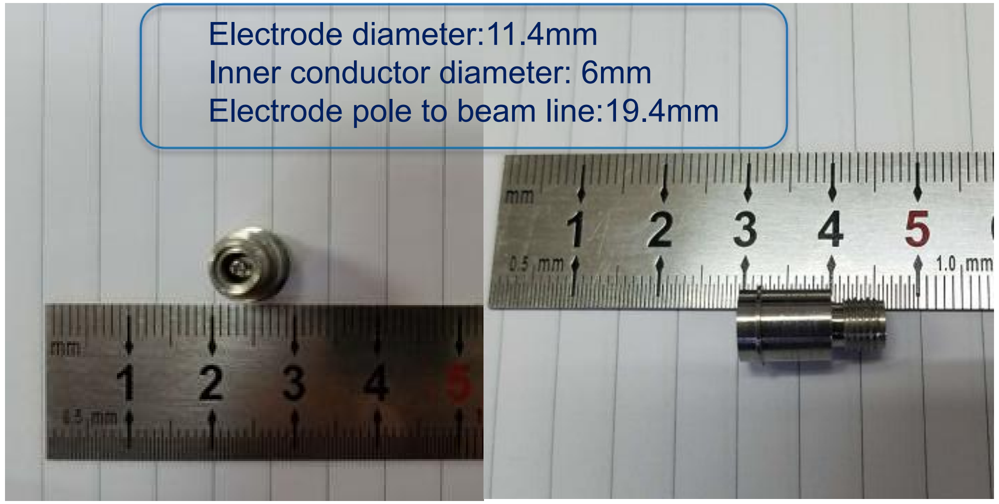
- ✓ Due to the short bunch length, signal has many resonance hump, signal amplitude proportional to the bunch charge.
- ✓ Signal intensity can be satisfied by CEPC MDI requirement.

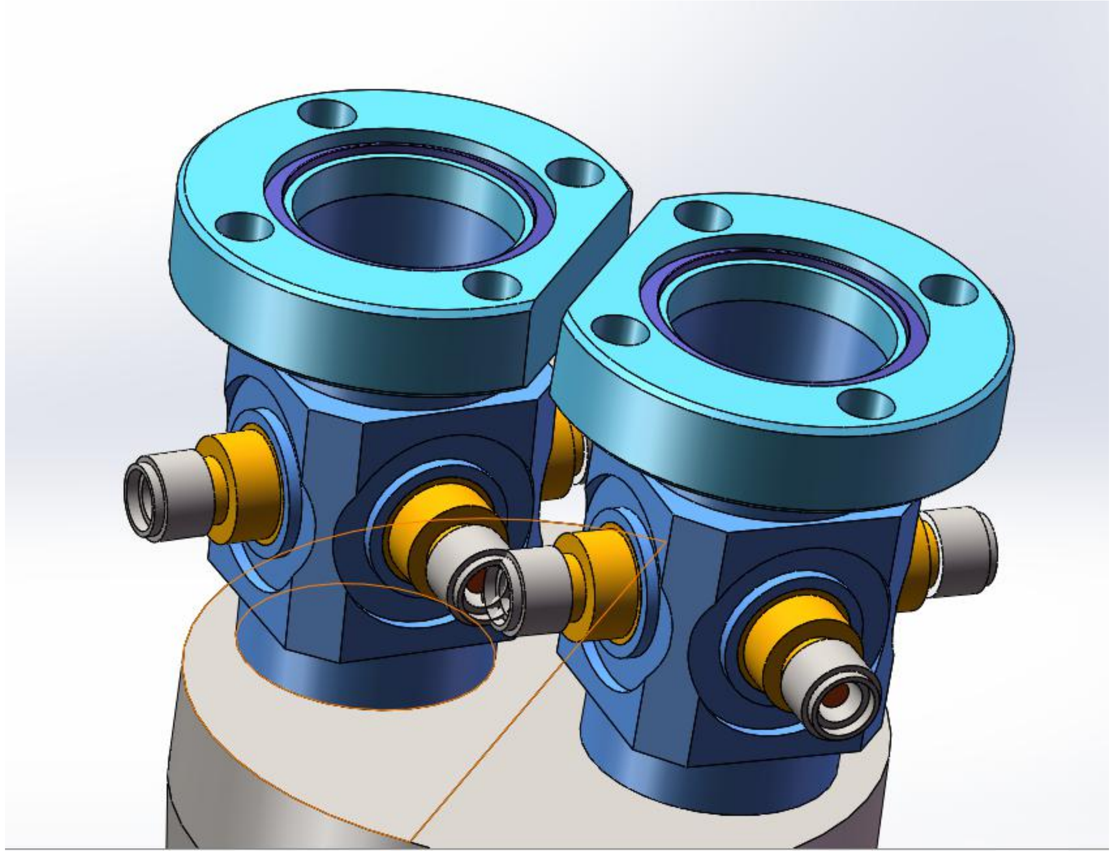
IP BPM-2

4 button electrodes structure



4 button electrodes size





- Monitoring the time when two beams arrive at the collision point, it is better to be consistent strictly.
- Space conflict for the inside two buttons, can be solved by the new position design for lumical and IR beam pipe.

MDI Components R&D Status

Name	status
Superconducting magnet QD0	Designed
Superconducting magnet QF1	Designed
Cryostat	Under design
Detector solenoid	Designed
Anti-solenoid	Designed
BPM	Under design
Lumical	Under design
IR vacuum chamber	Under design
Berrylium pipe	Under design
RVC(remote vacuum connection)	Under design
Shielding	Under design
Cooling system	Under design
Vacuum pump	Under design
Supporting system	Under design
Flange	Under design
Bellows	Under design
Alignment	Under design
Trimming support in SC magnet	Under design
HOM absorber	Under design
Auxiliary coils in SC magnet	Under design
Coating	Under design

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.
- 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.
- HOM of IR beam pipe has been simulated, water cooling and synchrotron radiation were considered and HOM absorber is under design.
- Synchrotron radiation and impedance are taken into account for collimators, collimator machanics structure preliminary designed.
- RVC preliminary design finished.
- Mechanics assembly procedure will be improved with detector group.
- Supporting system alignment accuracy ~120um, needs to be improved.
- IP BPM under design.

Thanks go to CEPC team and international partners and colleageus