香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

Institute of High Energy Physics
Chinese Academy of Sciences

HKUST JOCKEY CLUB
INSTITUTE FOR ADVANCED STUDY

CEPC MDI towards TDR

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for CEPC MDI group

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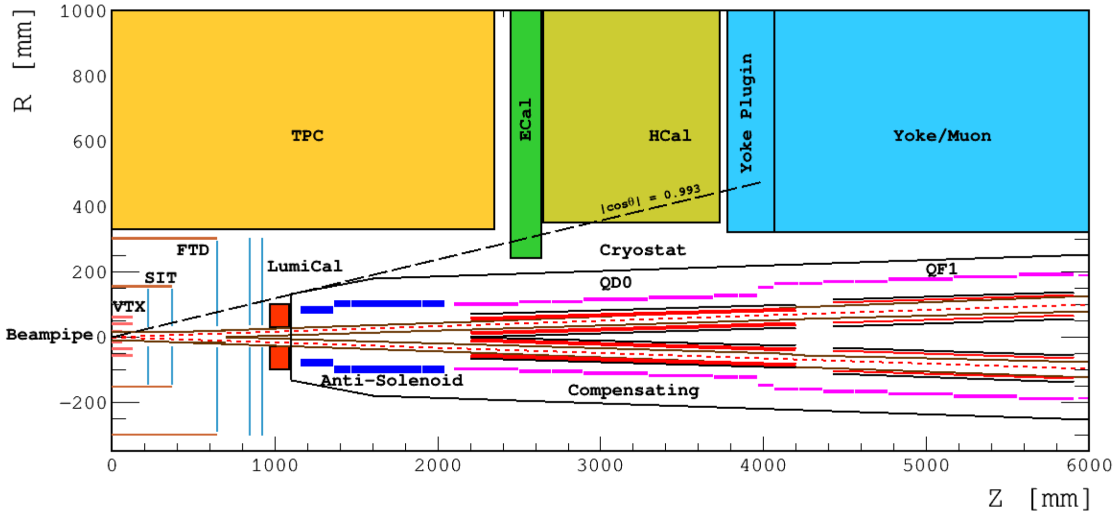
Outline

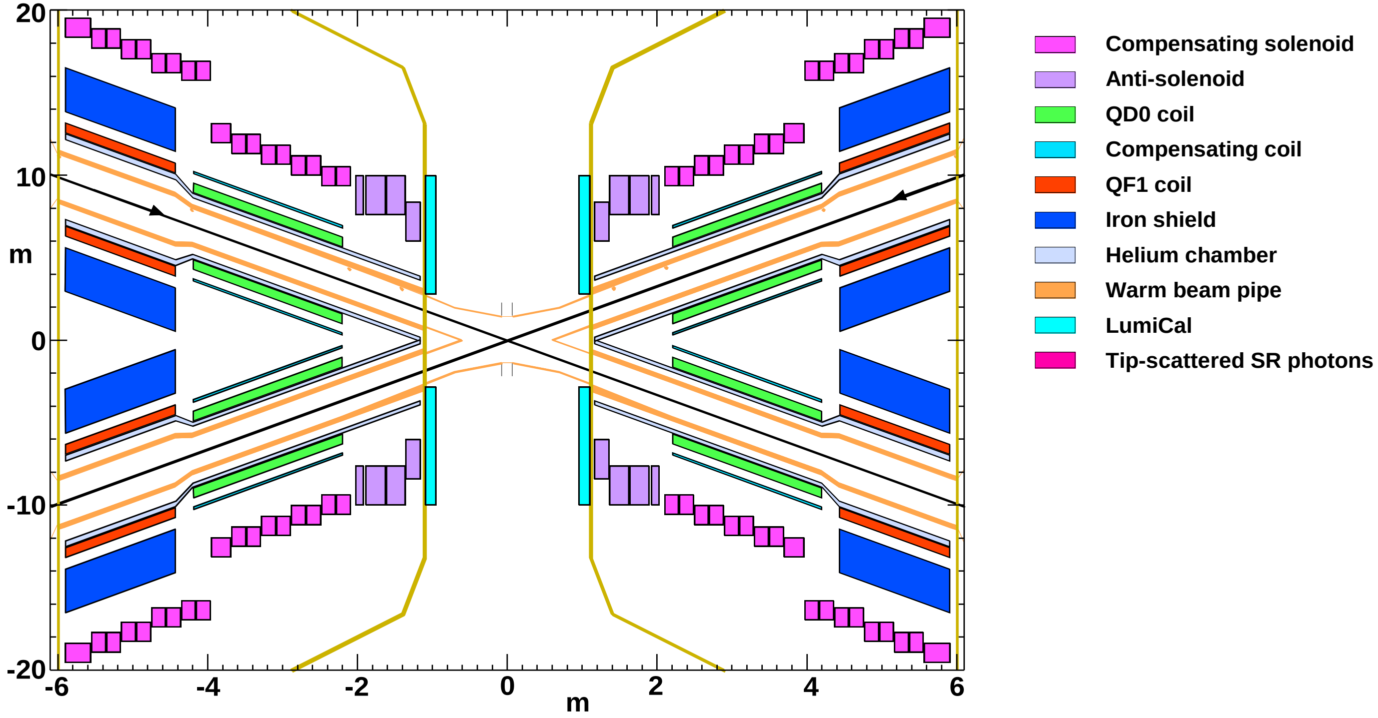
- MDI layout and IR design
- Synchrotron radiation and mask design
- Beam loss background and collimator design
- HOM absorber design
- Mechanics and assembly
- SC magnet supporting system
- IP BPM design
- Summary

MDI layout and IR design

With Detector solenoid



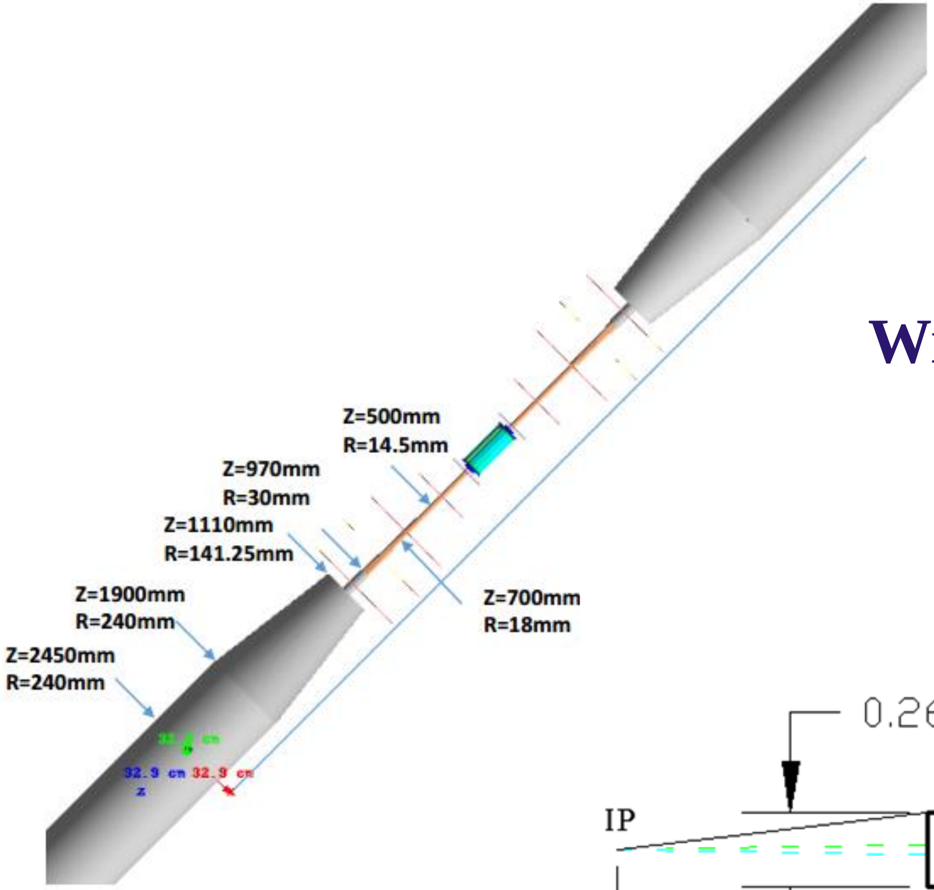
Without Detector solenoid
~cryostat in detail



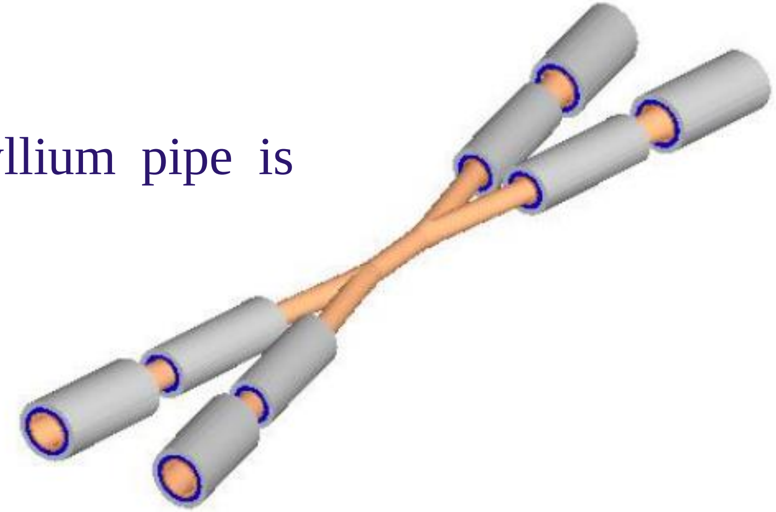
- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993.
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is 2.2m
- Lumical will be installed in longitudinal 0.95~1.11m, with inner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

- 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.

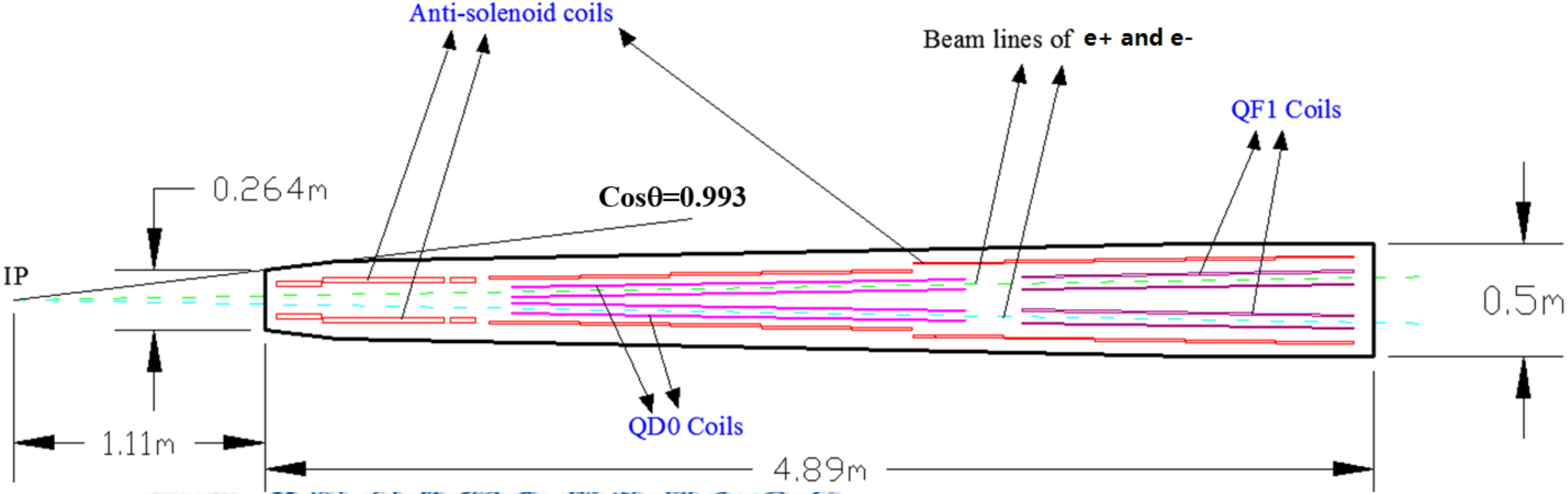
The design of interaction region



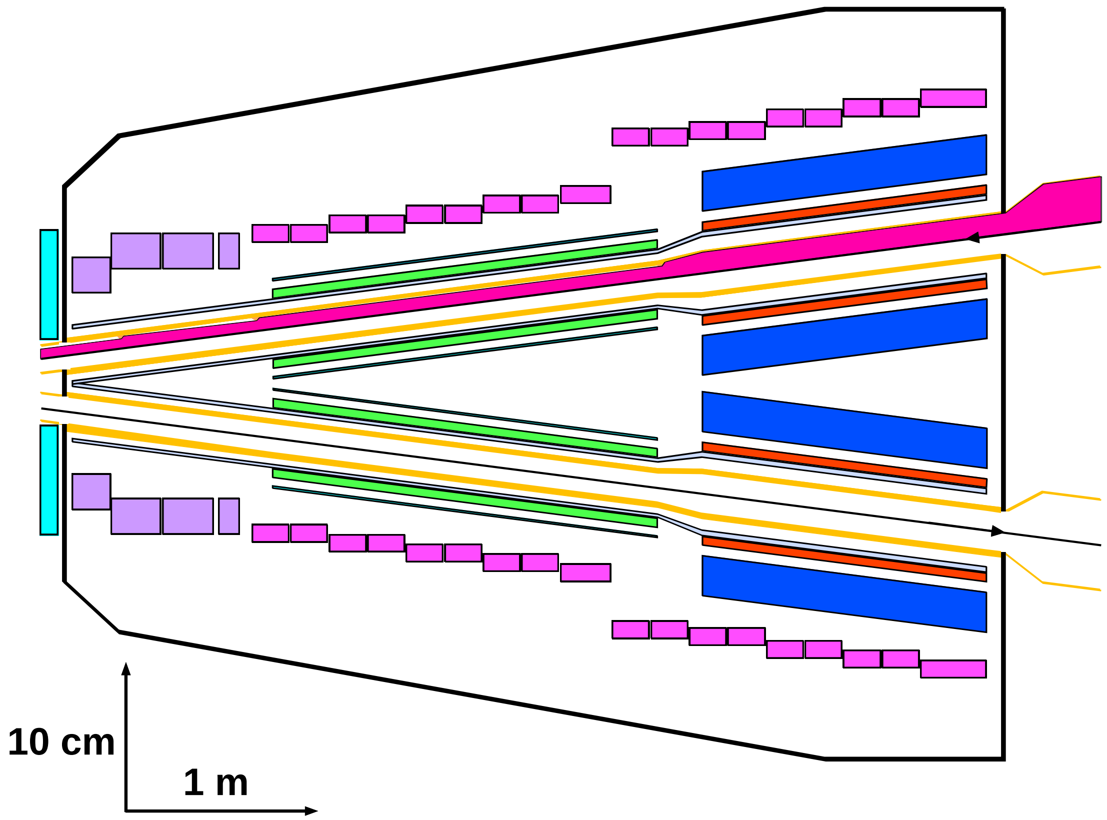
The inner diameter of the beryllium pipe is 28mm with the length of ±7cm.



Without tungsten shield.



SR from bends of IR

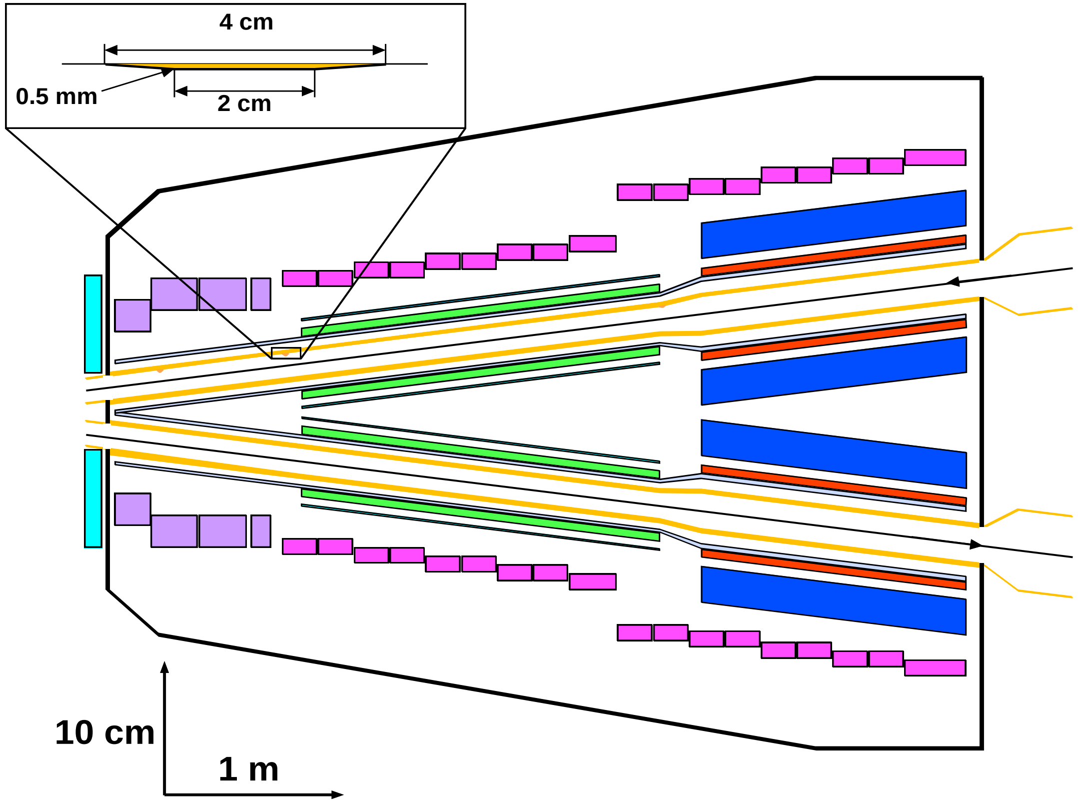


Surface	Power (W)	SR photons > 1 keV
Under QF1	2.51	1.01×10^{9}
Between QF1 and QD0	40.04	1.63×10^{10}
Under QD0	8.08	3.26×10^{9}
In front of QD0	4.45	1.80×10^{9}

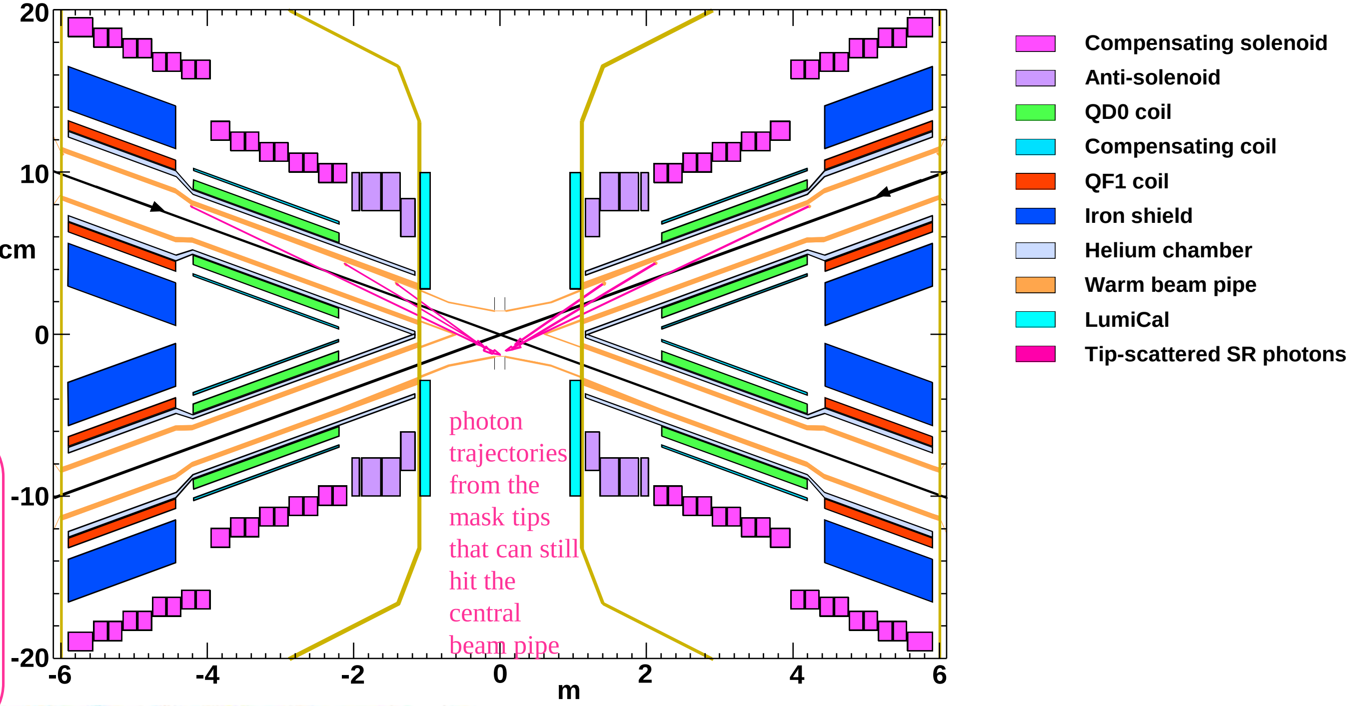
- ✓ A significant fraction of these incident photons will forward scatter from the beam pipe surface and hit the central Be beam pipe (a cylinder located ±7 cm around the IP with a radius of 14 mm).
- ✓ Masks are needed.

- ✓ 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

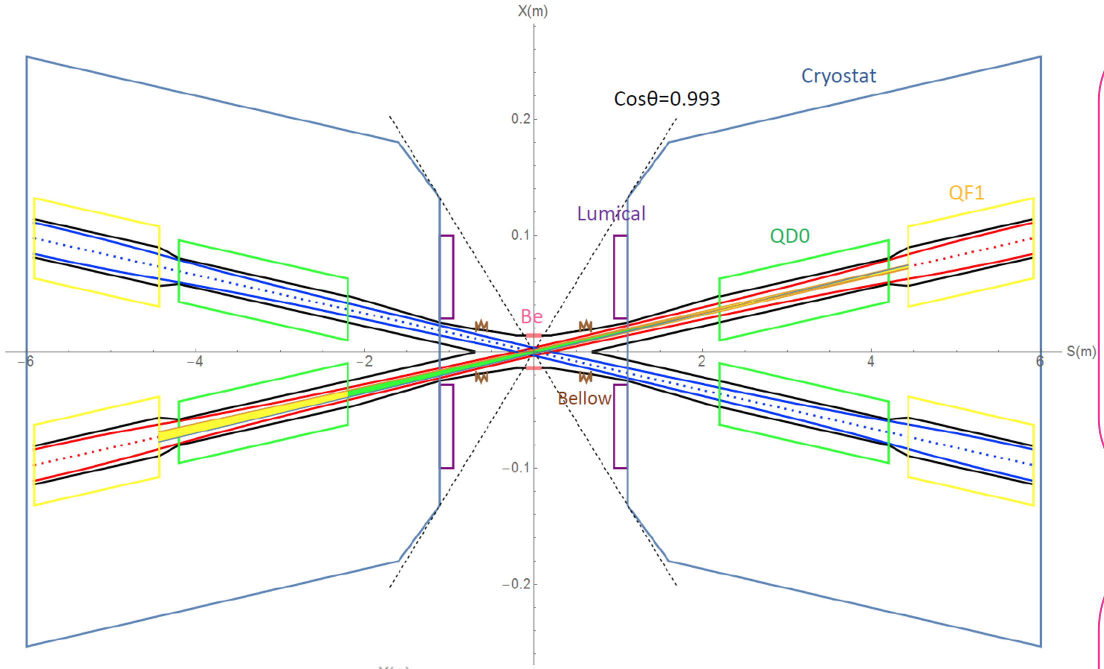


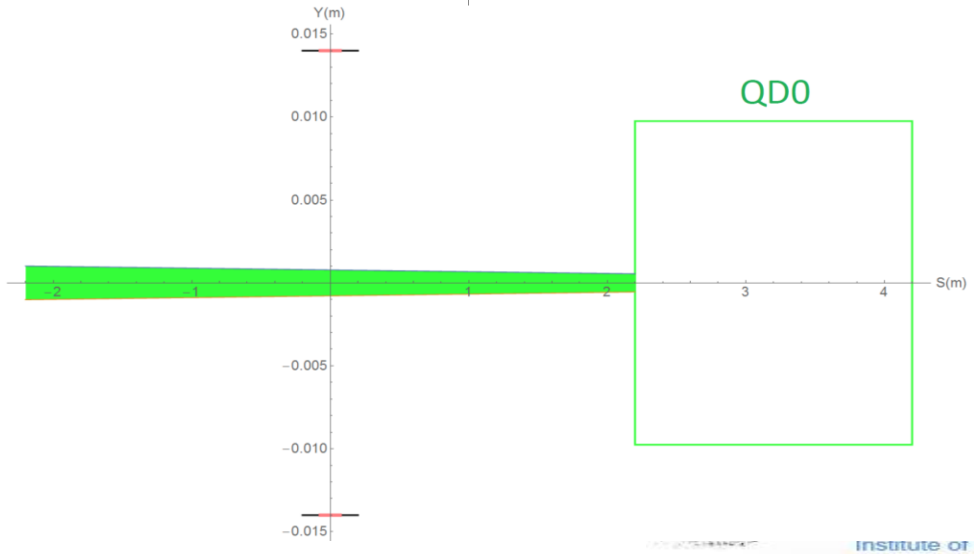
3 mask tips are added to shadow the beam pipe wall reduces the number of photons that hit the Be beam pipe from 2×10^4 to about 200 (100 times lower).



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

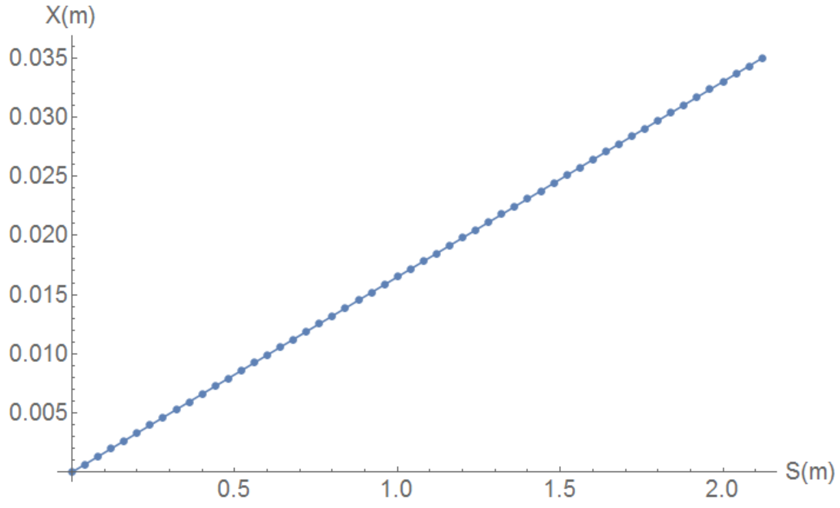


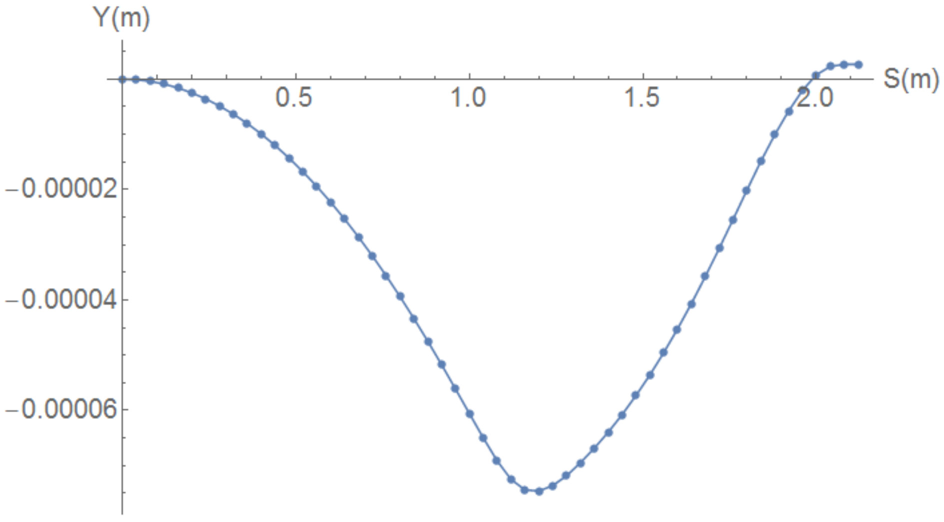


- ✓ The total SR power generated by the QD magnet is 639W in horizontal and 166W in vertical. The critical energy of photons are about 1.3 MeV and 397keV in horizontal and vertical.
- ✓ The total SR power generated by the QF1 magnet is 1567W in horizontal and 42W in vertical. The critical energies of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

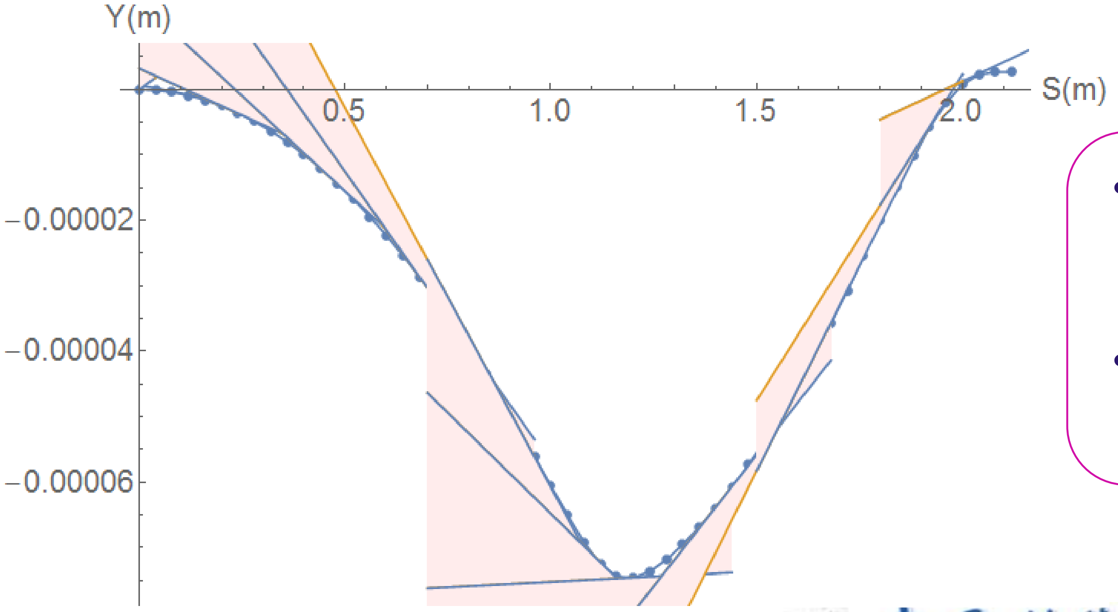
- ✓ No SR photons within 10 σ_x directly hitting or once-scattering to the detector beam pipe.
- ✓ Collimators for the beam loss will cut beam to 13σ_x. SR photons generated from 10σ_x to 13σ_x will hit downstream of the IR beam pipe, and the once-scattering photons will not go into the detector beam 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.

SR from solenoid combined field



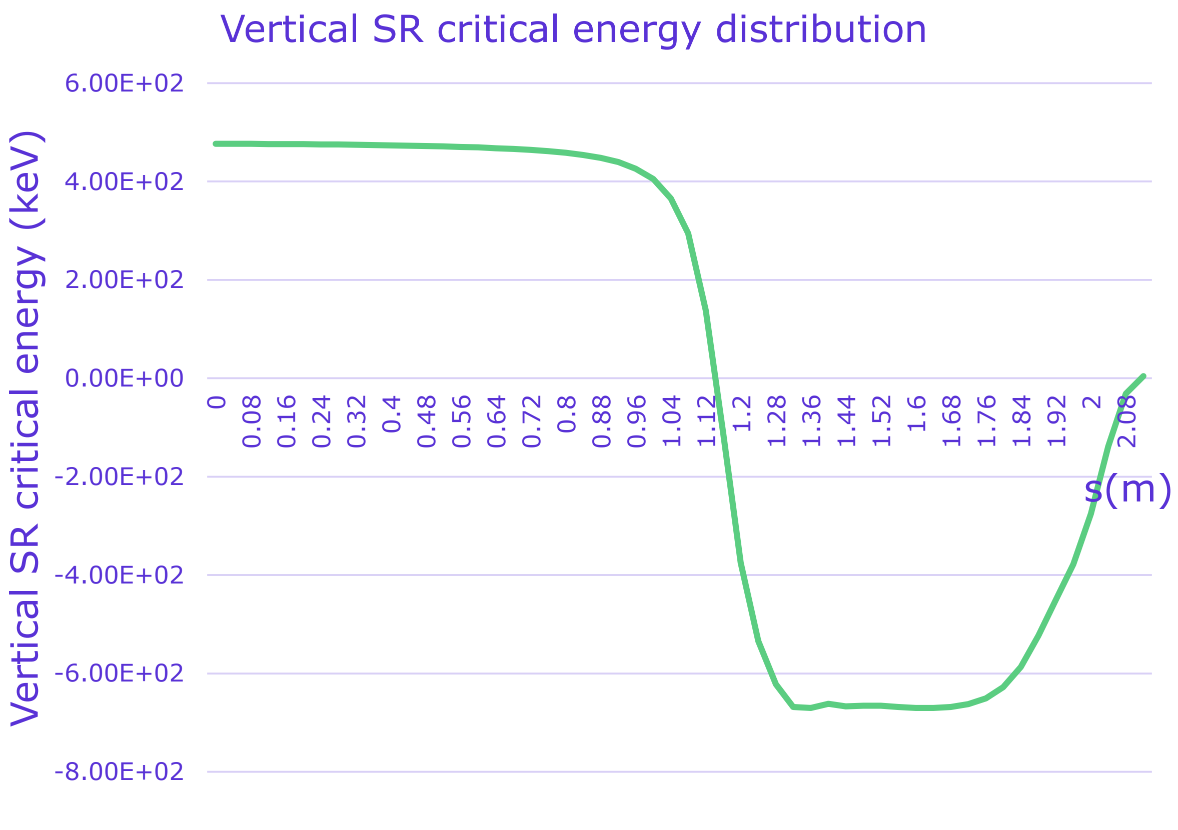


Horizontal trajectory will coupled to the vertical.

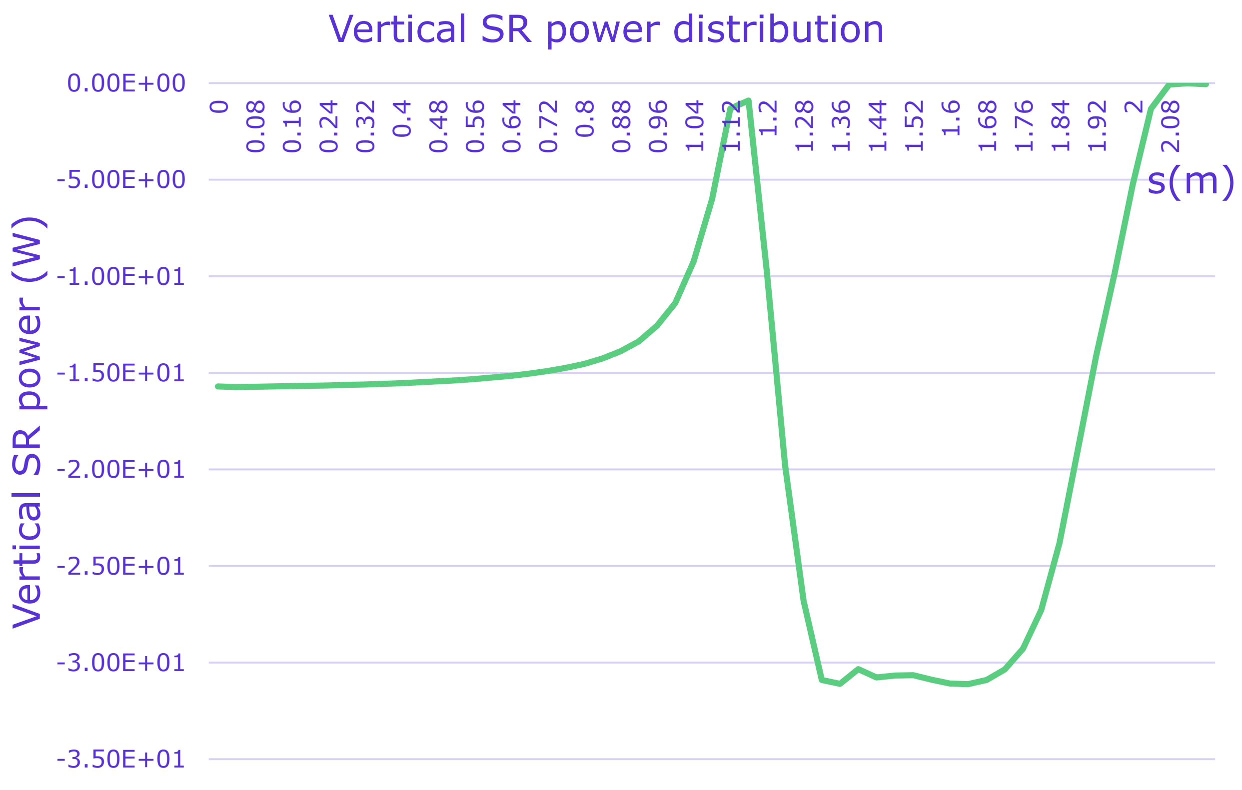


- Due to the sol+anti-sol field strength quite high, maximum~4.24T, transverse magnetic field component is quite high.
- SR from vertical trajectory in sol+anti-sol combined field should be taken into account.

SR critical energy and power distribution

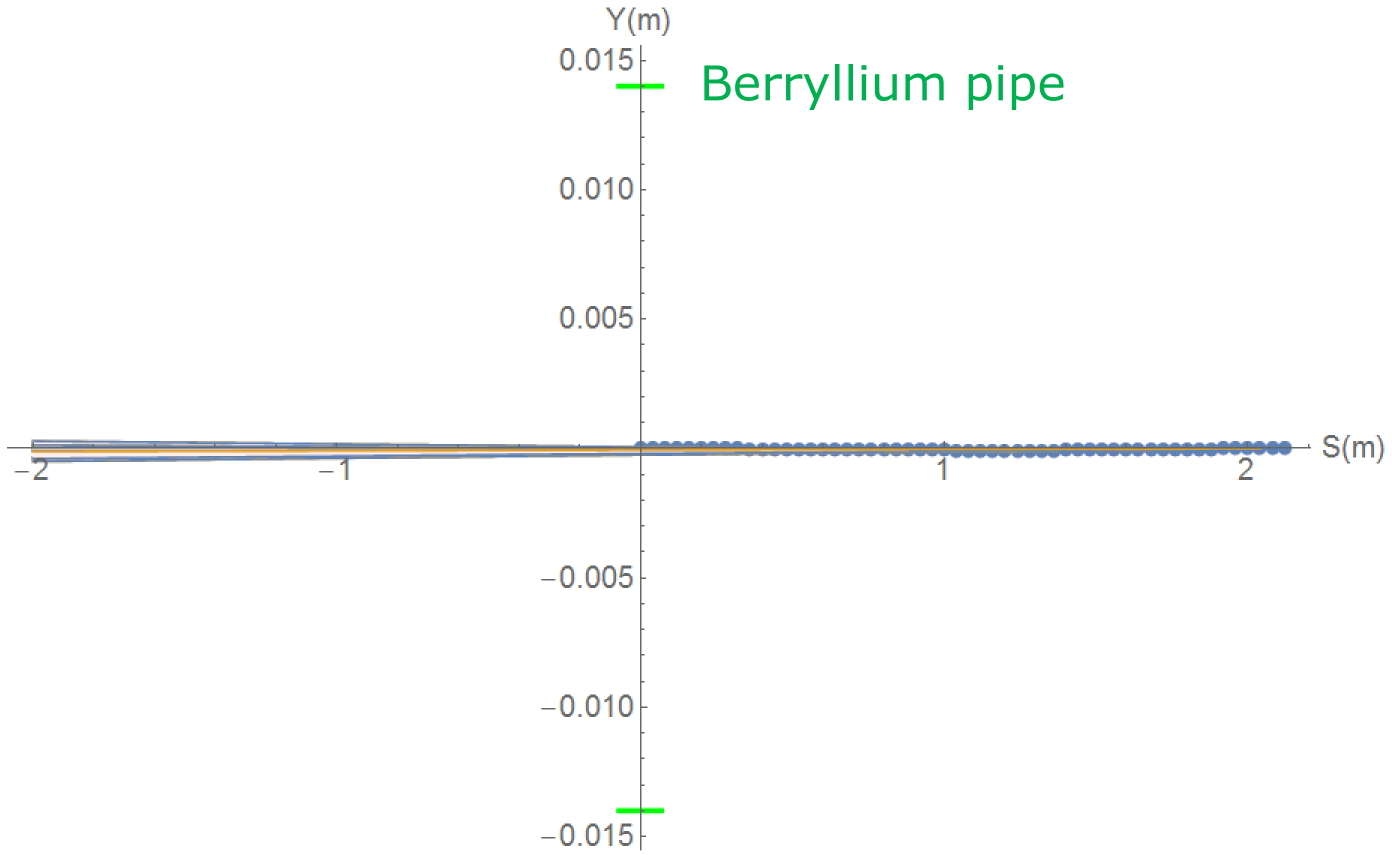


Maximum: 670keV



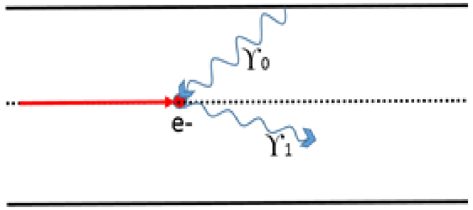
Maximum: 31W

SR from solenoid combined field

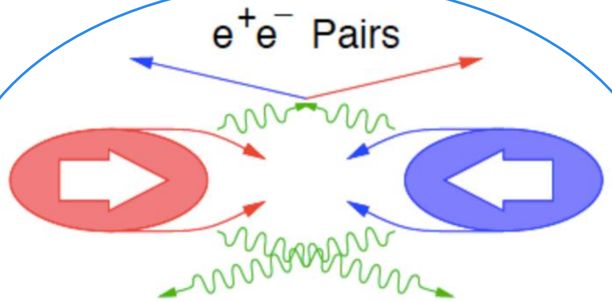


- SR sector is focused in a very narrow angle from -116urad to 131urad
- SR will not hit Berryllium pipe, and not cause background to detector.
- SR will hit the beam pipe ~213.5m downstream from IP
- Water cooling is needed.

Beam loss Backgrounds at CEPC



Beam-Thermal photon scattering



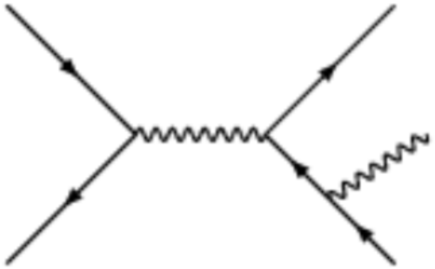
Beamstrahlung

IP1

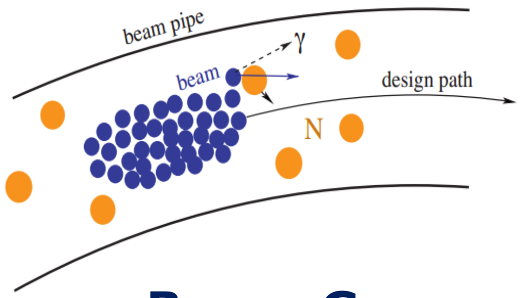
242 bunches
Revolution frequency: **2997**Hz
1.5×10^{11} particles/Bunch
L: $3 \times 10^{34} cm^{-2} s^{-1}$

IP3

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



Radiative Bhabha scattering

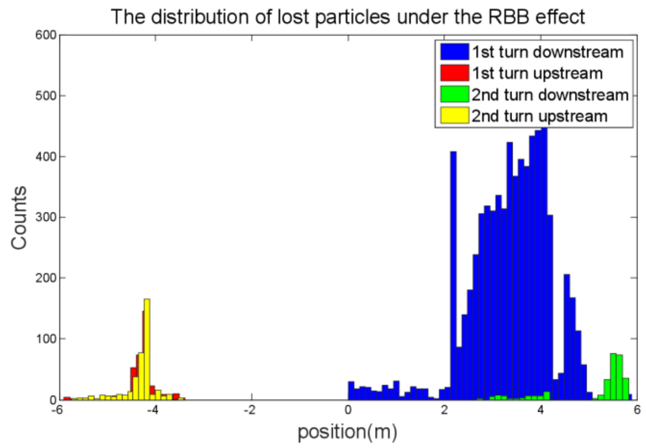


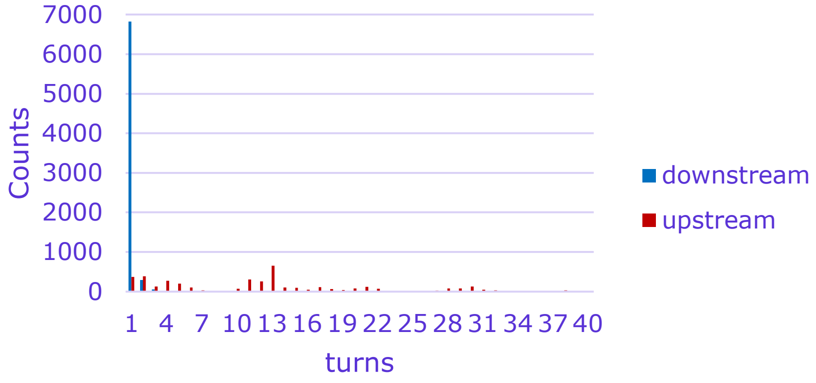
Beam-Gas Scattering

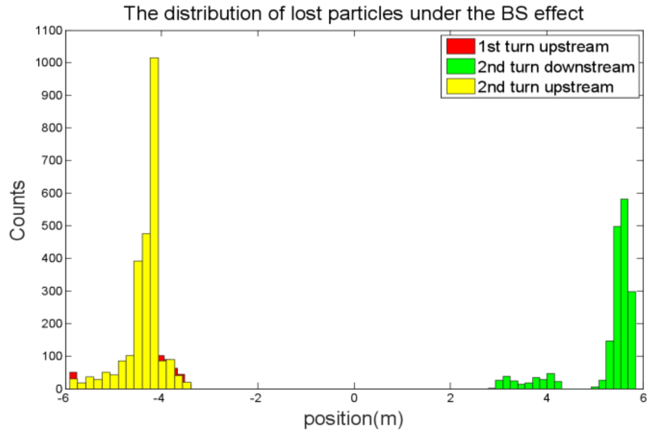
CEPC beam lifetime

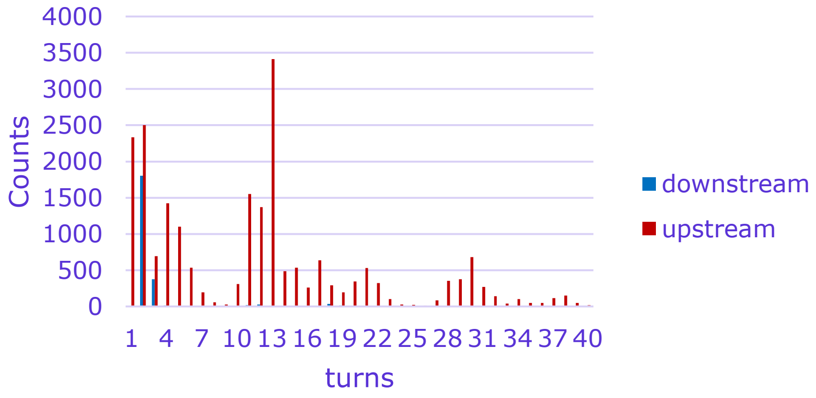
	Beam lifetime	others
Quantum effect	>1000 h	
Touscheck effect	>1000 h	
Beam-Gas（Coulomb scattering）	>400 h	Residual gas CO，10^{-7}Pa
Beam-Gas（bremsstralung）	63.8 h	
Beam-Thermal photon scattering	50.7 h	
Radiative Bhabha scattering	74 min	
Beamstrahlung	80 min	

Loss particles due to RBB & BS







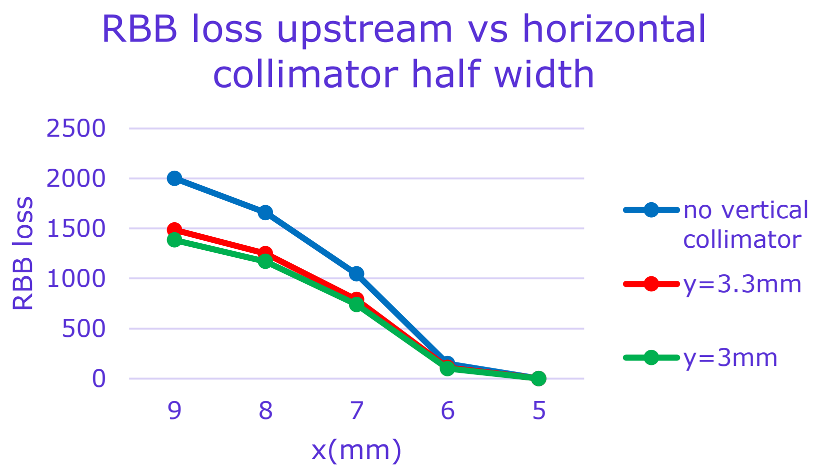


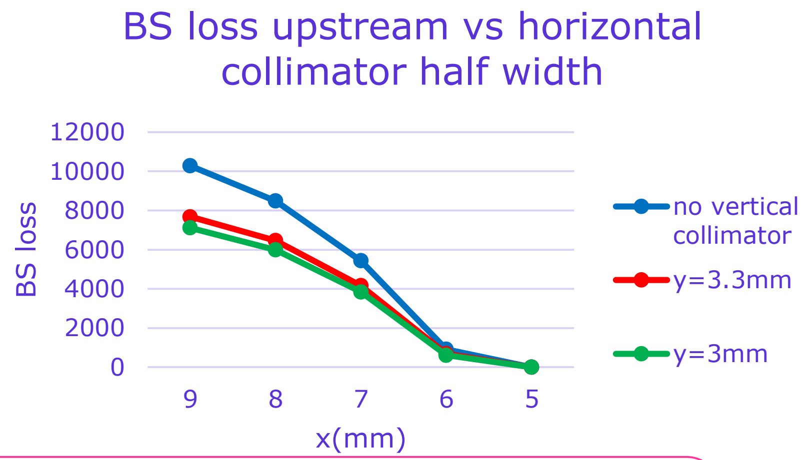
- For RBB, most the events lost in the detector immediately. A few particles with high energy will lost near the IP after one revolution for a small energy loss.
- For BS, energy spread distribution close to the energy acceptance, the beam loss particles not appeared in the downstream of first turn.
- Compared to the one turn's tracking, more particles get lost in the upstream region of the IR.
- Although pretty large fraction of events lost in the downstream region, the radiation damage for detector component is tolerable.
- 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.

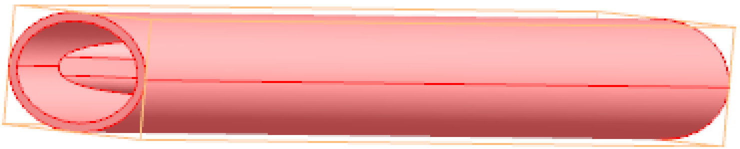
Collimator design

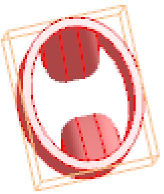
- Beam stay clear region: 18 σ_x+3mm, 22 σ_y+3mm
- Impedance requirement: slope angle of collimator < 0.1
- To shield big energy spread particles, phase between pair collimators: $\pi/2+n*\pi$
- Collimator design in large dispersion region: $\sigma=\sqrt{\varepsilon\beta+(D_x\sigma_e)^2}$

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



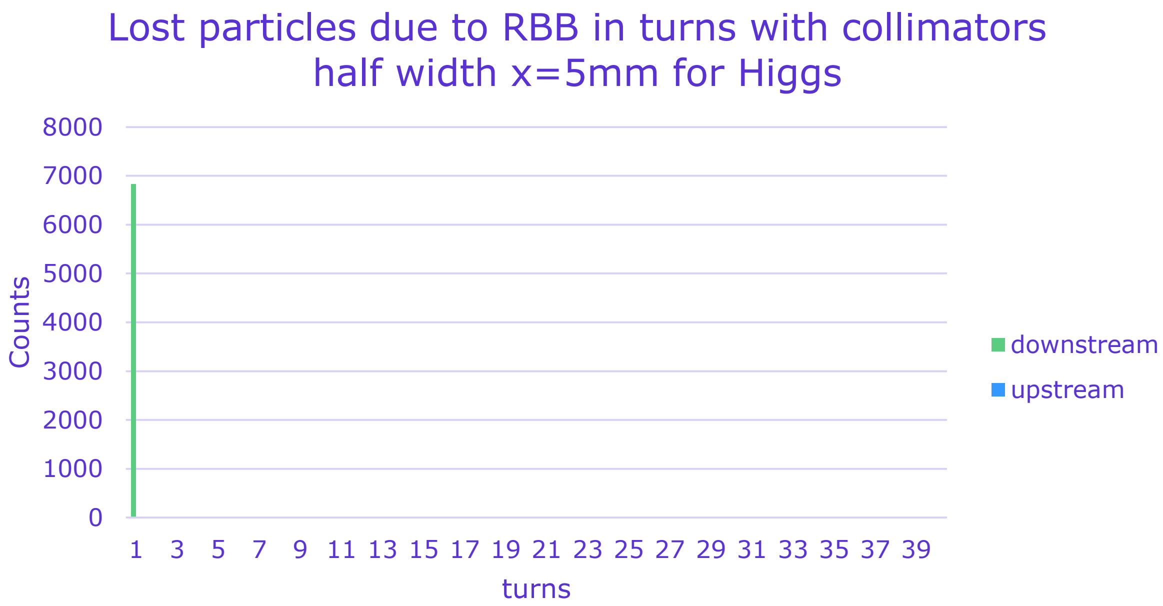


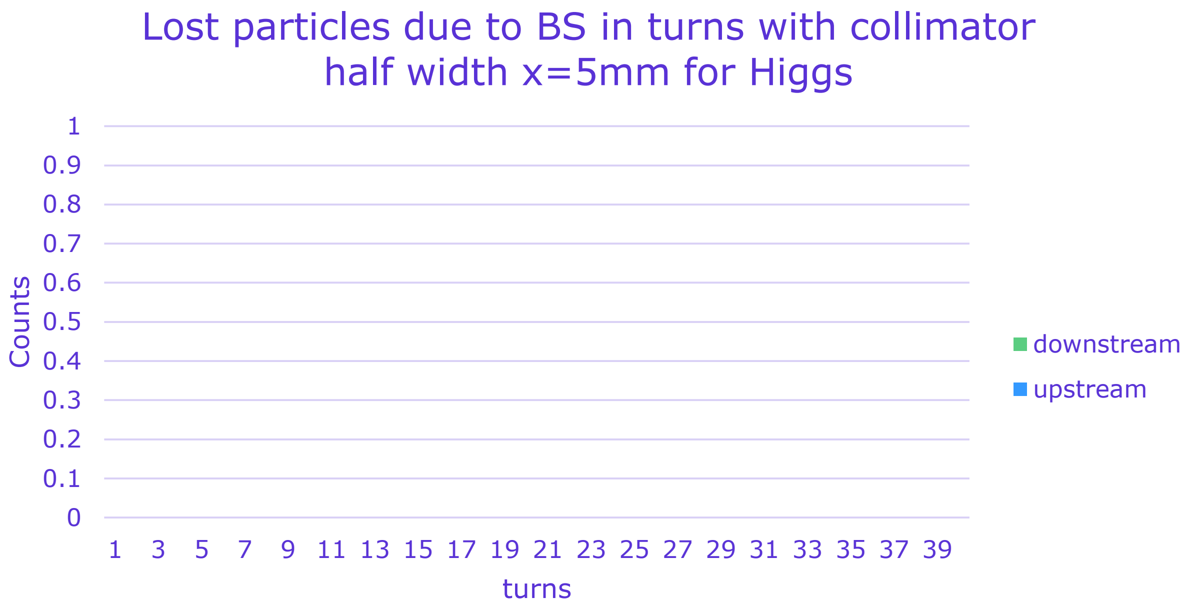




- Only horizontal collimator are selected, vertical collimators are not needed.
- Vertical collimators are usually placed very close to the beam, no vertical collimators to avoid transverse mode coupling instability.

RBB and BS loss with collimators for Higgs



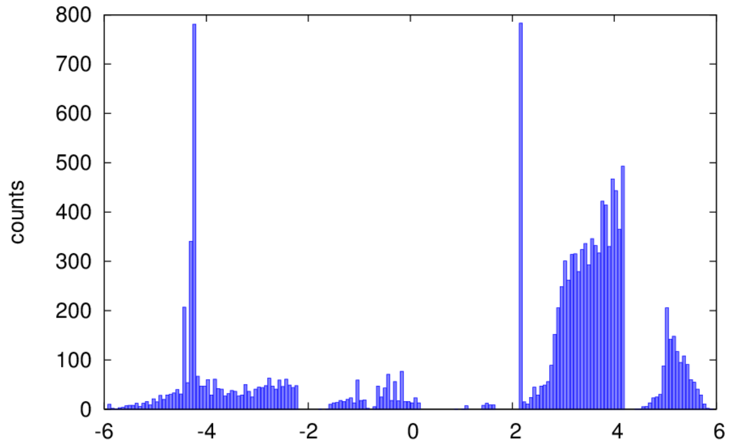


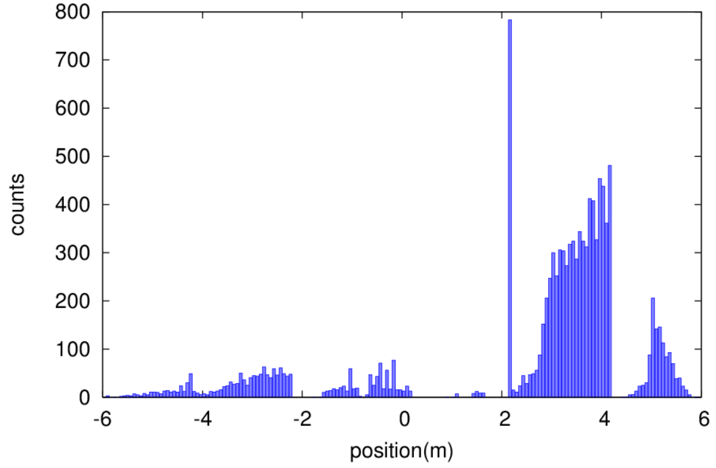
- horizontal collimator half width 5mm(13σ_x)
- The collimators will not have effect on the beam quantum lifetime.
- The lost particles has been reduced to a very low level with the system of collimators, especially in the upstream of the IP.
- Although the beam loss in the downstream of the IP is still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

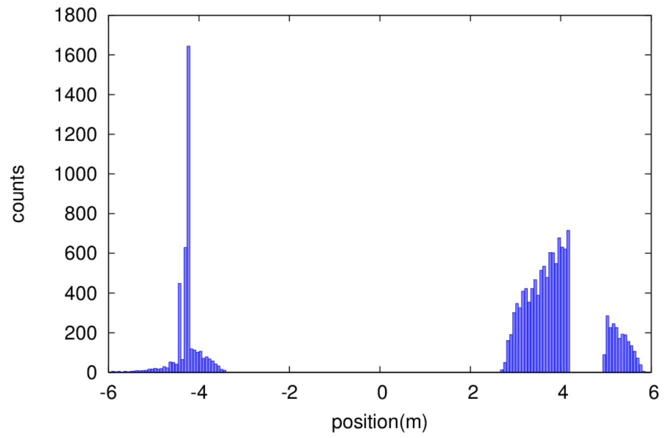
Without collimators | With collimators

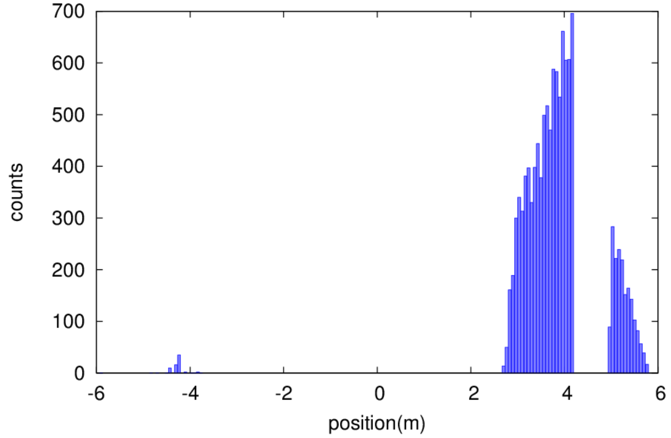
Beam-Gas bremsstrahlung





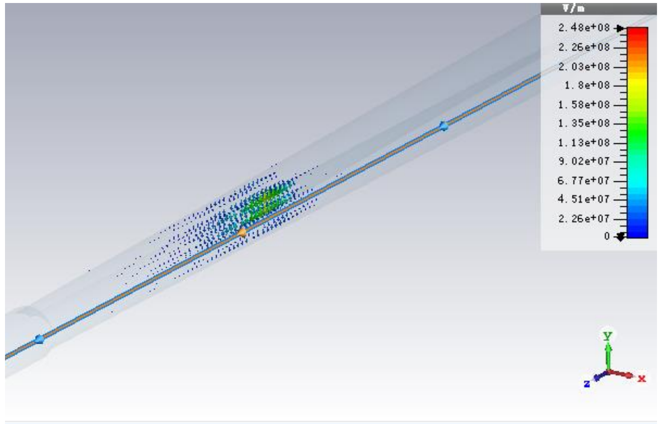
Beam-Thermal photon scattering

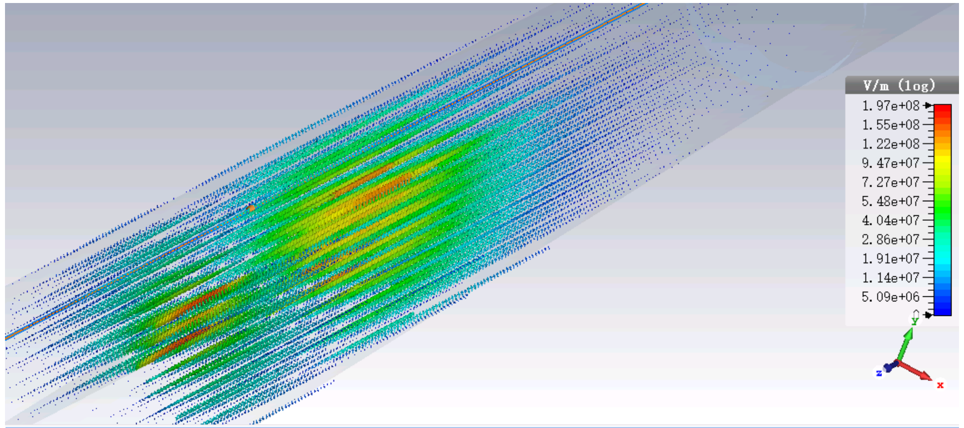




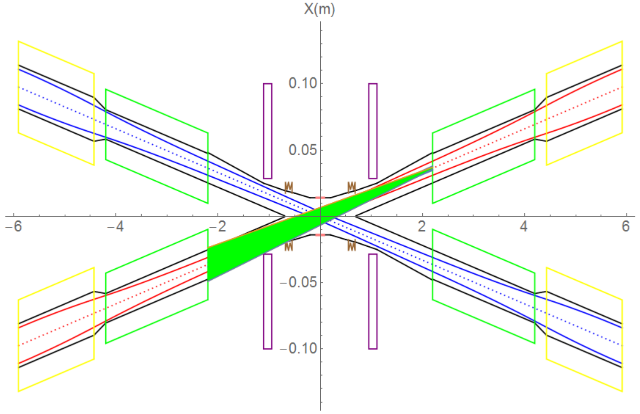
- The lost particles has been reduced to a very low level with collimators, especially in the upstream of the IP, can be accepted by the detector.
- Although the beam loss in the downstream of the IP is still remained, the radiation damage and the detector background are not serious, since the direction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

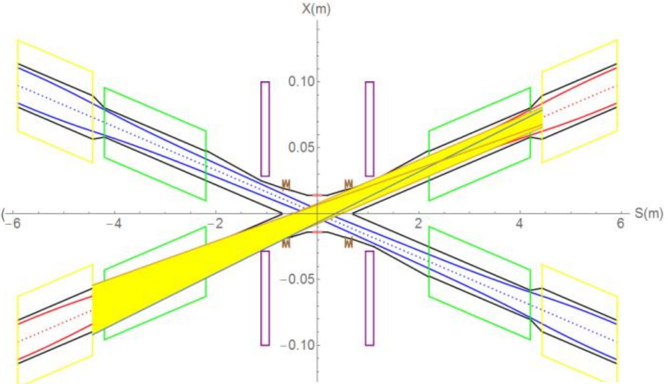
HOM absorber

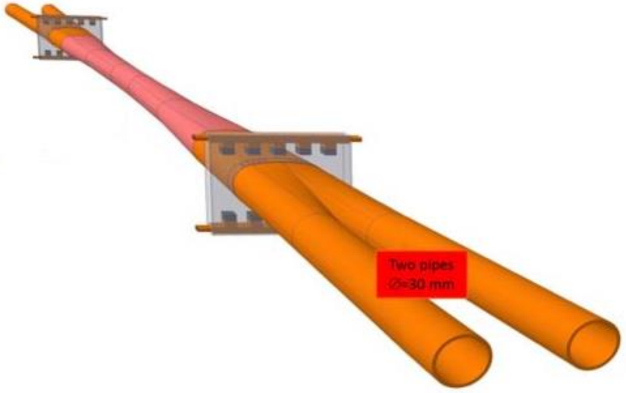


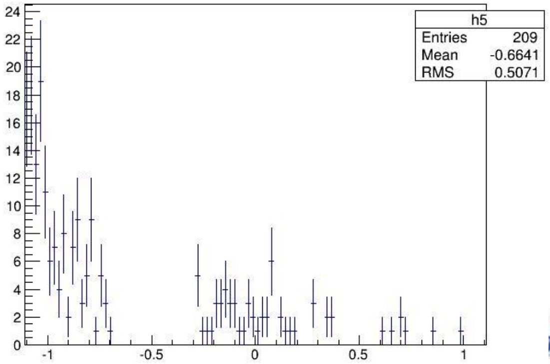


- TE mode, at crotch point (z~±700mm)
- Frenquency 3.2996GHz，Qe=1.42x10^{12}
- This mode is trapped mode.
- HOM absorber is needed，water cooling system considered.
- With the high order mode of this TE mode, eg. 3.715GHz.





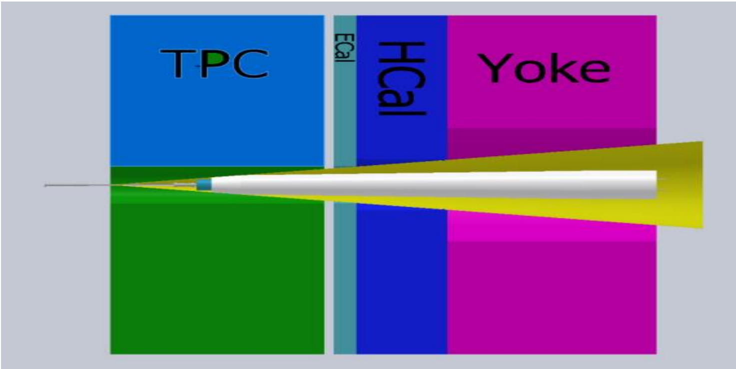


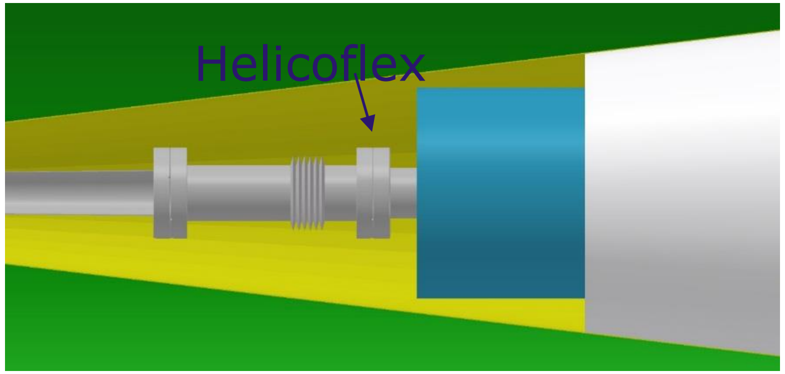


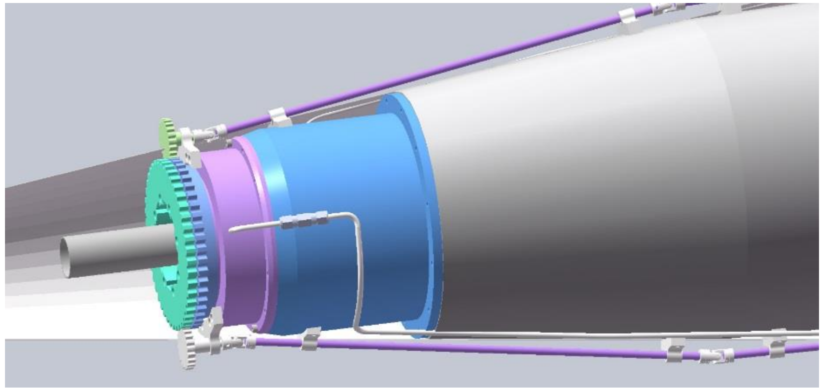
Synchrotron radiation from Final doublet magnets and reflection part from mask，HOM absorber radiation resistance requirements ?

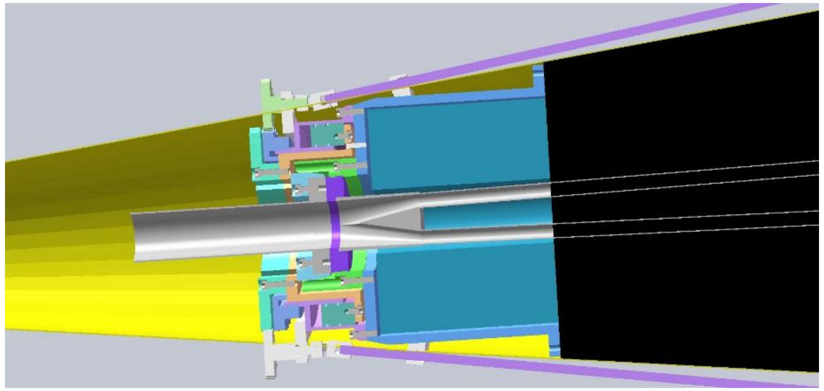
- HOM absorber design refer to FCC, under development
- Distance from IP is 70cm~90cm in crotch section，space conflict with RVC and IP BPM needs to be fixed.
- Impedance

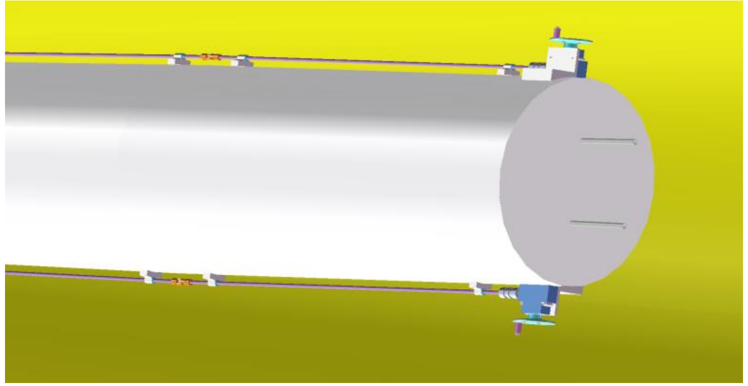
IR mechanics assembly

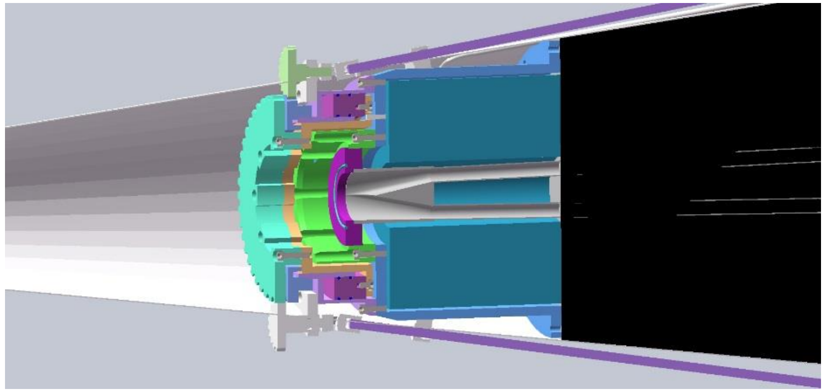





RVC head and drive gear


cutaway view of RVC head

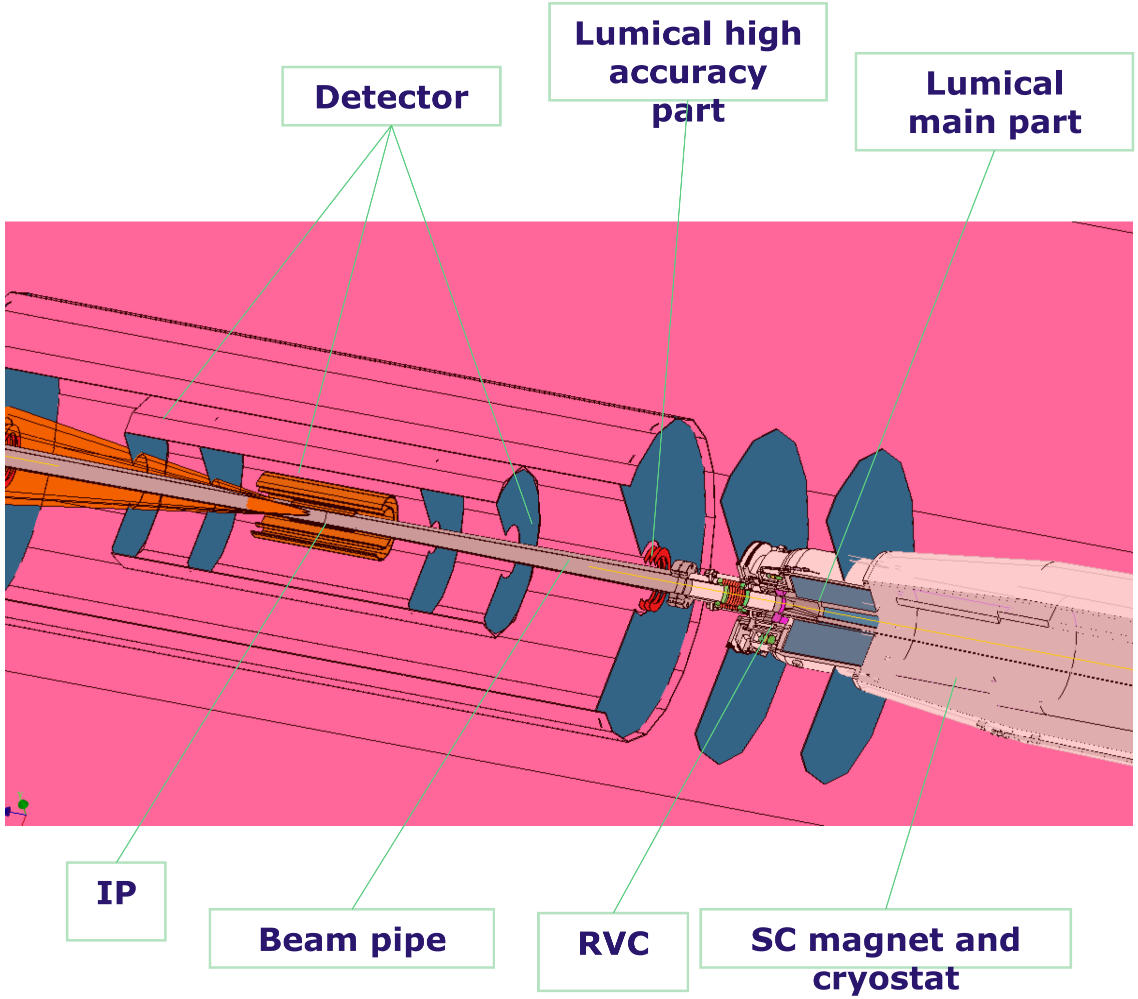

RVC tail/handwheel structure


Cutaway view of moving part

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

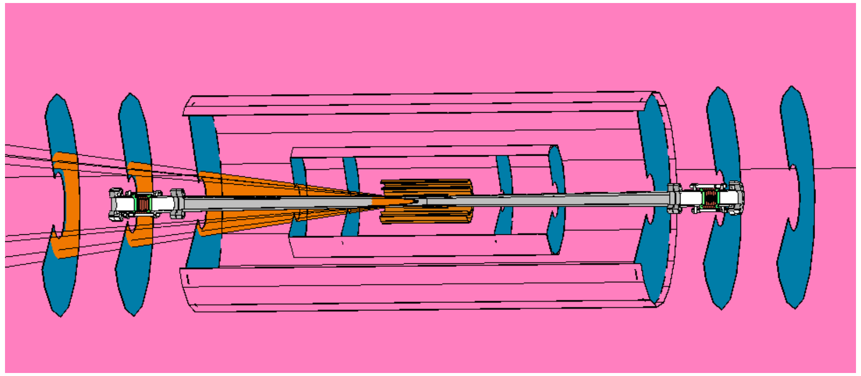
IR mechanics assembly

- **CEPC MDI Lumical and accelerator components conflict in both position and alignment accuracy has been fixed: Lumical can be separated into 2 parts, one part with high precision installed and aligned with Be vacuum chamber, the other part 50~100kg can be installed and aligned with cryostat. And can be calibrated with IP BPM(<1um), Be pipe installed with detector.**

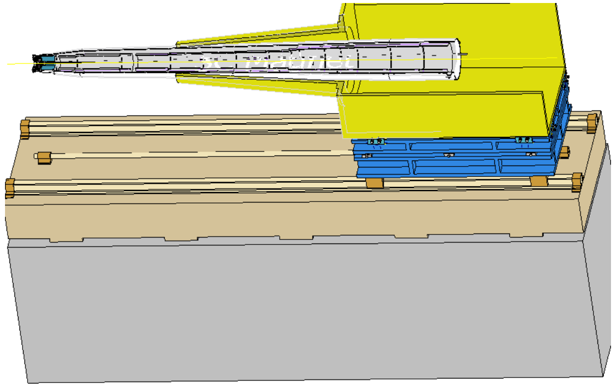


IR mechanics assembly

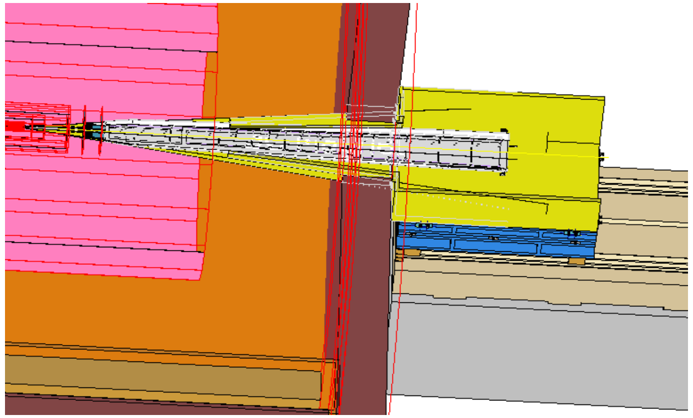
1： Be and detector assembly and alignment， Lumical high accuracy part installed with Be pipe （Detector assembly can use the end cap.）



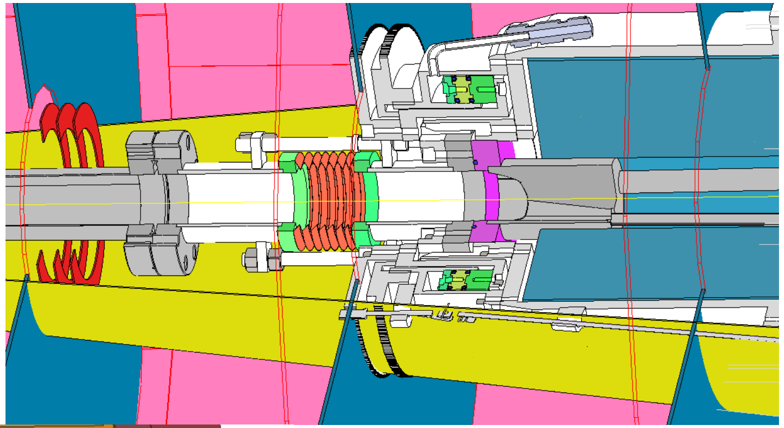
2： SC magnet、 Lumical main part aligned and assembly with RVC， installed on supporting system and aligned.



3： components in the second step with supporting system move to the setting position.

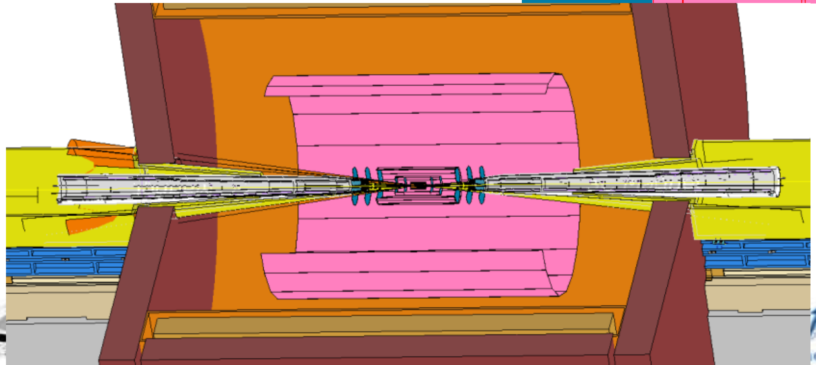


4： Beam pipe one side connected with cryostat using RVC.



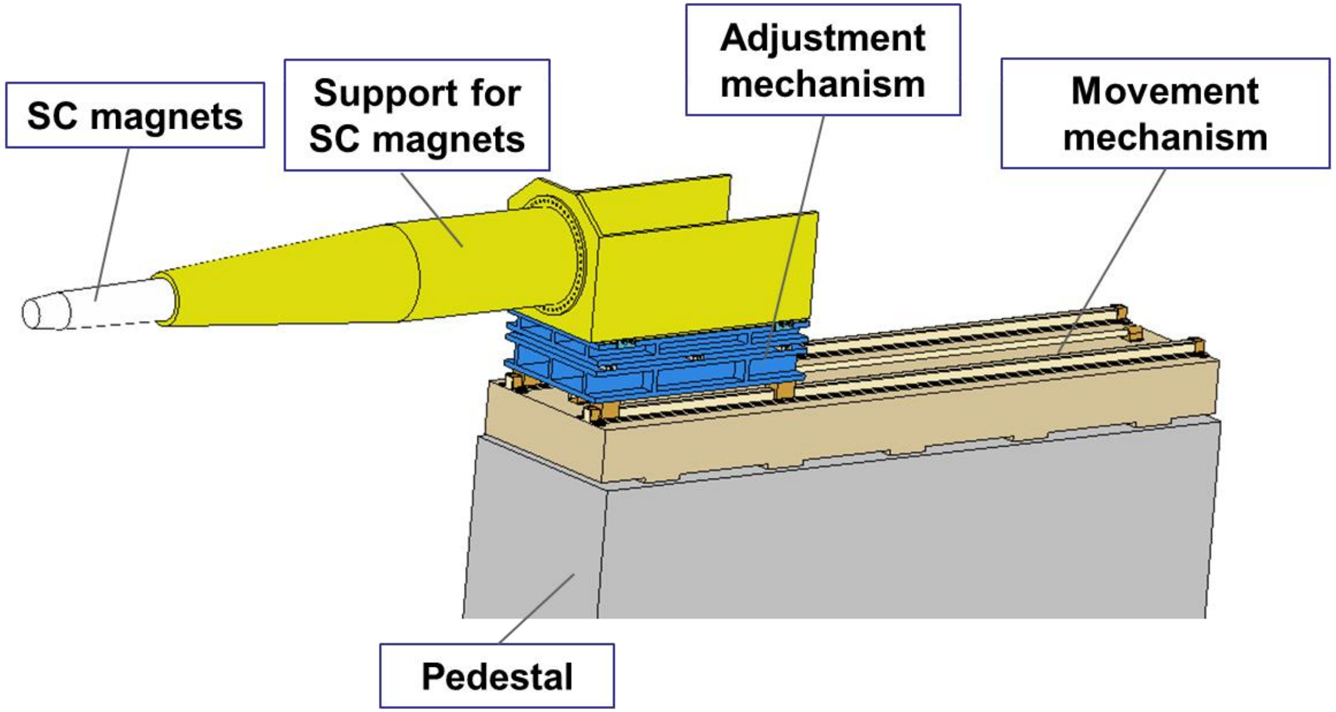
5： Repeat the 2~4 step in the other side

6： technical detection， completed.

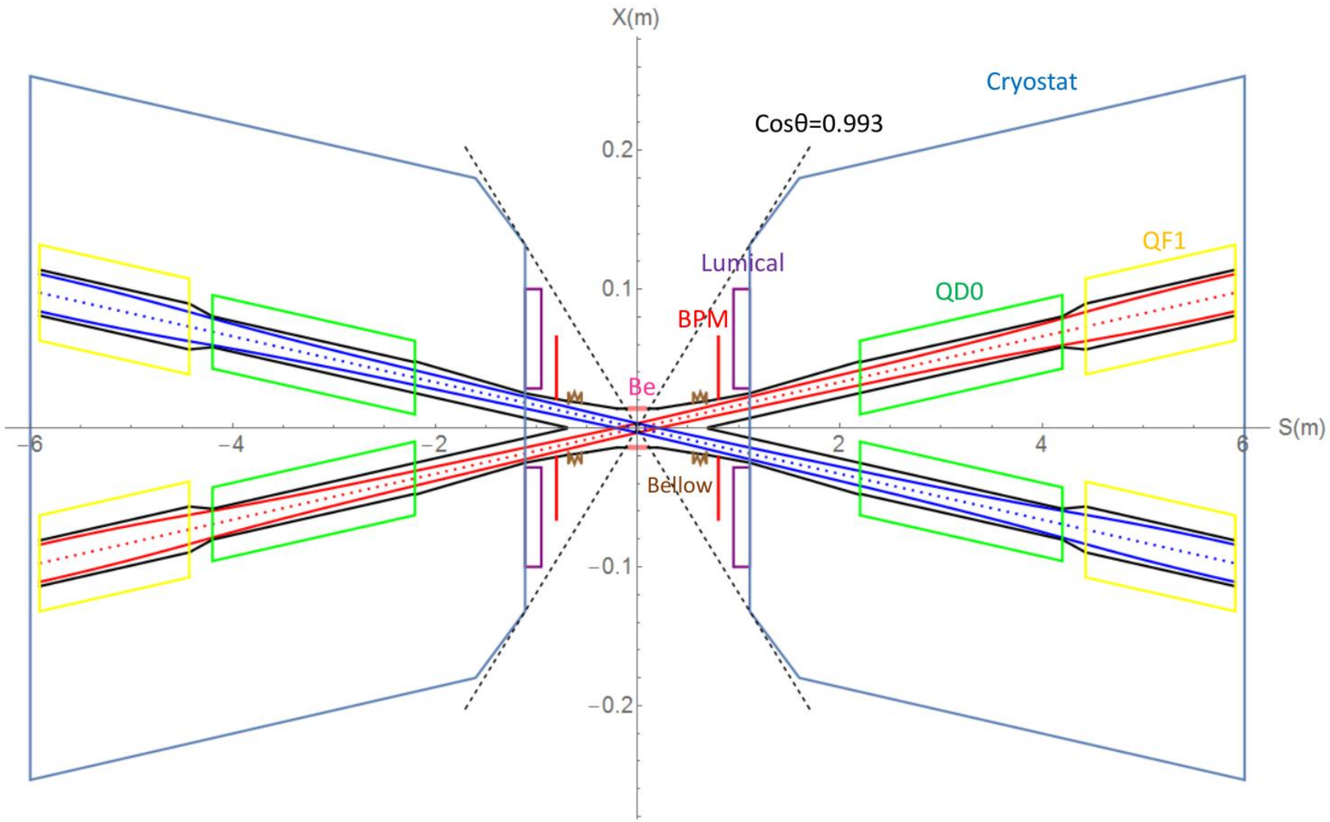


SC magnet supporting system

- 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



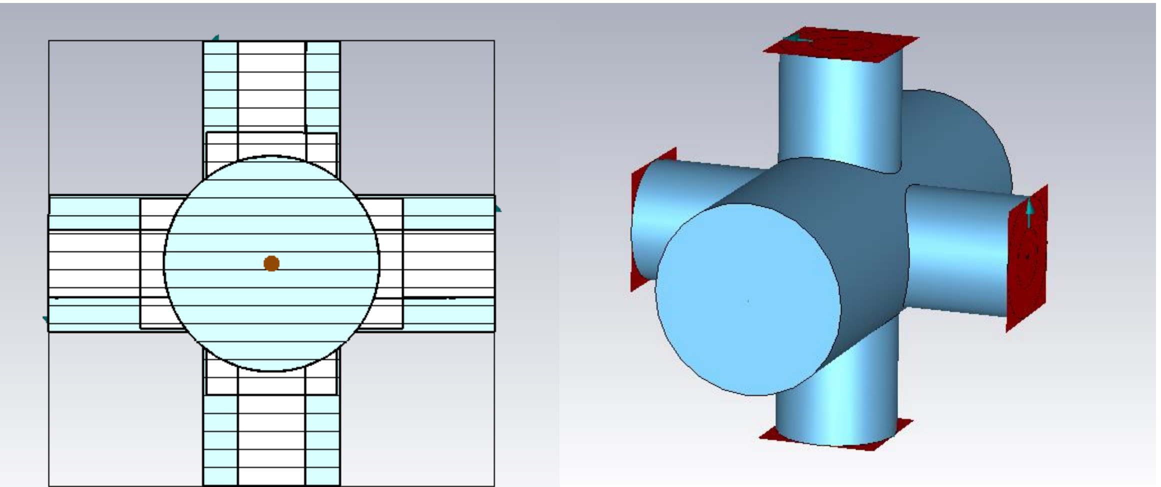
IP BPM



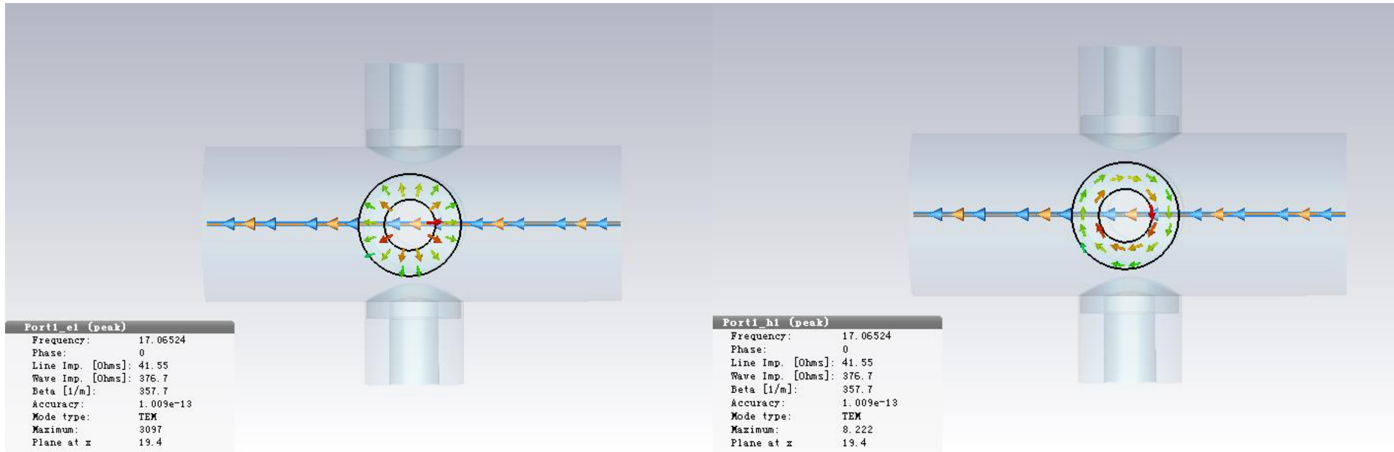
- Considering response time and calibration difficulty, two 4 button electrodes BPM at each side of CEPC IR is adopted.
- Most of CEPC IR beam pipe are cylinder or conic, only the part from 70cm to 95cm is special shape.
- There is a bellows for the requirements of installation in the crotch region, 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

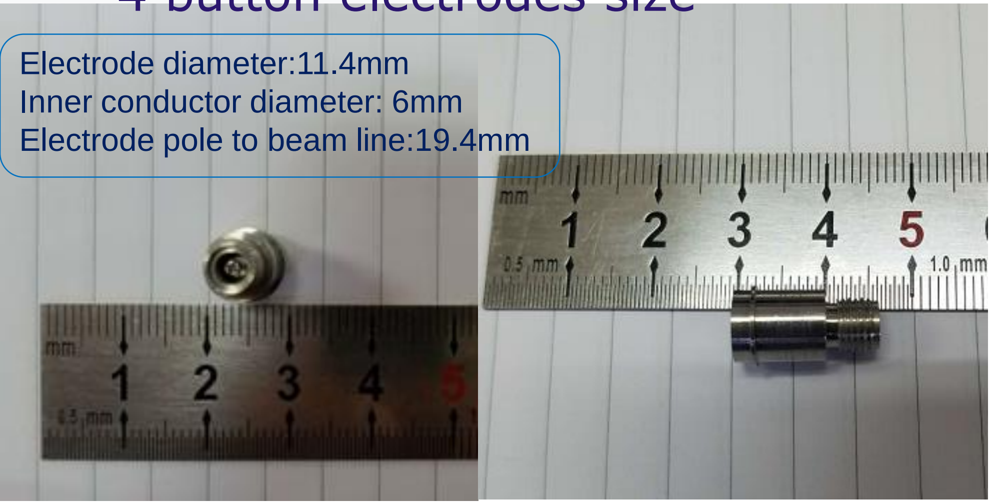


Electromagnetic field at electrodes

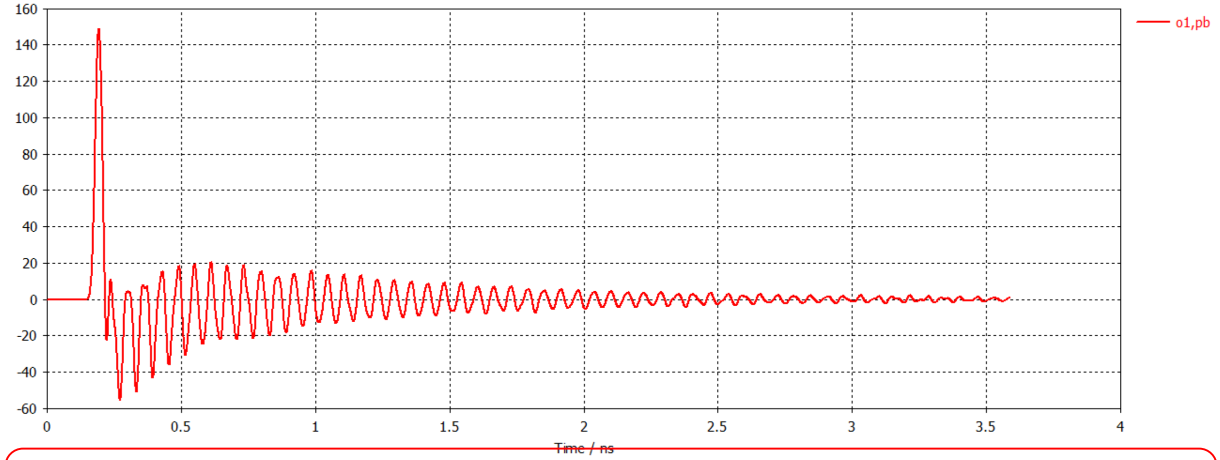


4 button electrodes size

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



Electrodes signal(bunch length 2.68mm)



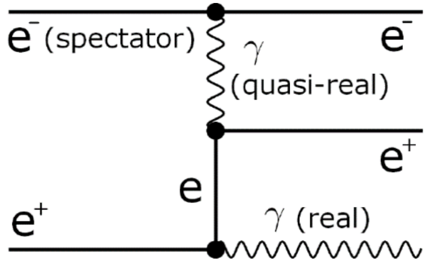
Due to the short bunch length, signal has many resonance hump, signal amplitude proportional to the bunch charge.

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

中国科学院高能物理研究所
Institute of High Energy Physics, Chinese Academy of Sciences

Luminosity monitoring

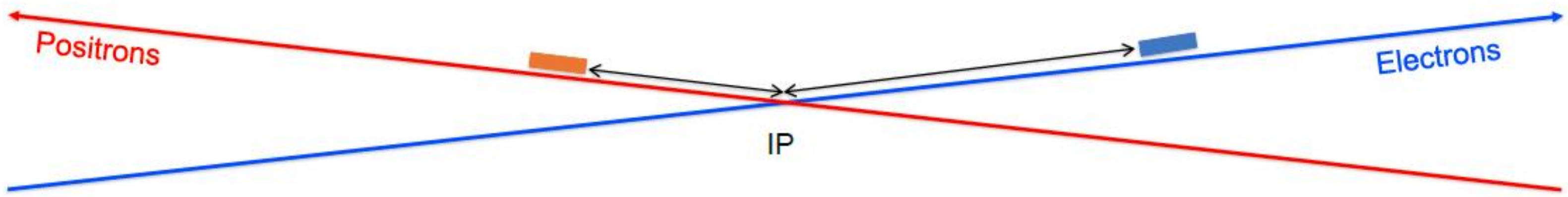
- **Relative luminosity monitoring (machine tuning, feedback…)**
  - Fast, precise, realtime
  - Train-integrated-luminosity
  - Bunch-integrated-luminosity



- **Radiative Bhabha process at vanishing photon scattering angle**
  - Proportional to luminosity
  - Large cross-section

- **Techniques and experiences**
  - ZDLM at BEPC-II
  - ZDLM (scintillator & Cherenkov, analog) and LumiBelle2 (diamond, digital) at SuperKEKB

- **Plans**
  - Figure out the requirement of the luminosity monitoring
  - Luminosity monitoring system
  - Search for the best candidate position for the luminosity monitor
  - Study on the signals / backgrounds



MDI components 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
Luminosity monitoring	Under design
IR vacuum chamber	Physics designed
Berrylium pipe	Physics designed
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.
- HOM of IR beam pipe has been simulated, water cooling was considered and HOM absorber is under design.
- 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 design of Remote Vacuum Connection(RVC) is finished. And preliminary procedures of mechanics assembly are under studying.
- Towards TDR, many of the MDI components are under development.

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Thanks