Institute of High Energy Physics
Chinese Academy of Sciences

CEPC MDI

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On behalf of CEPC MDI group

65th ICFA Advanced Beam Dynamics Workshop
on High Luminosity Circular e^+e^- Colliders
(eeFACT2022)
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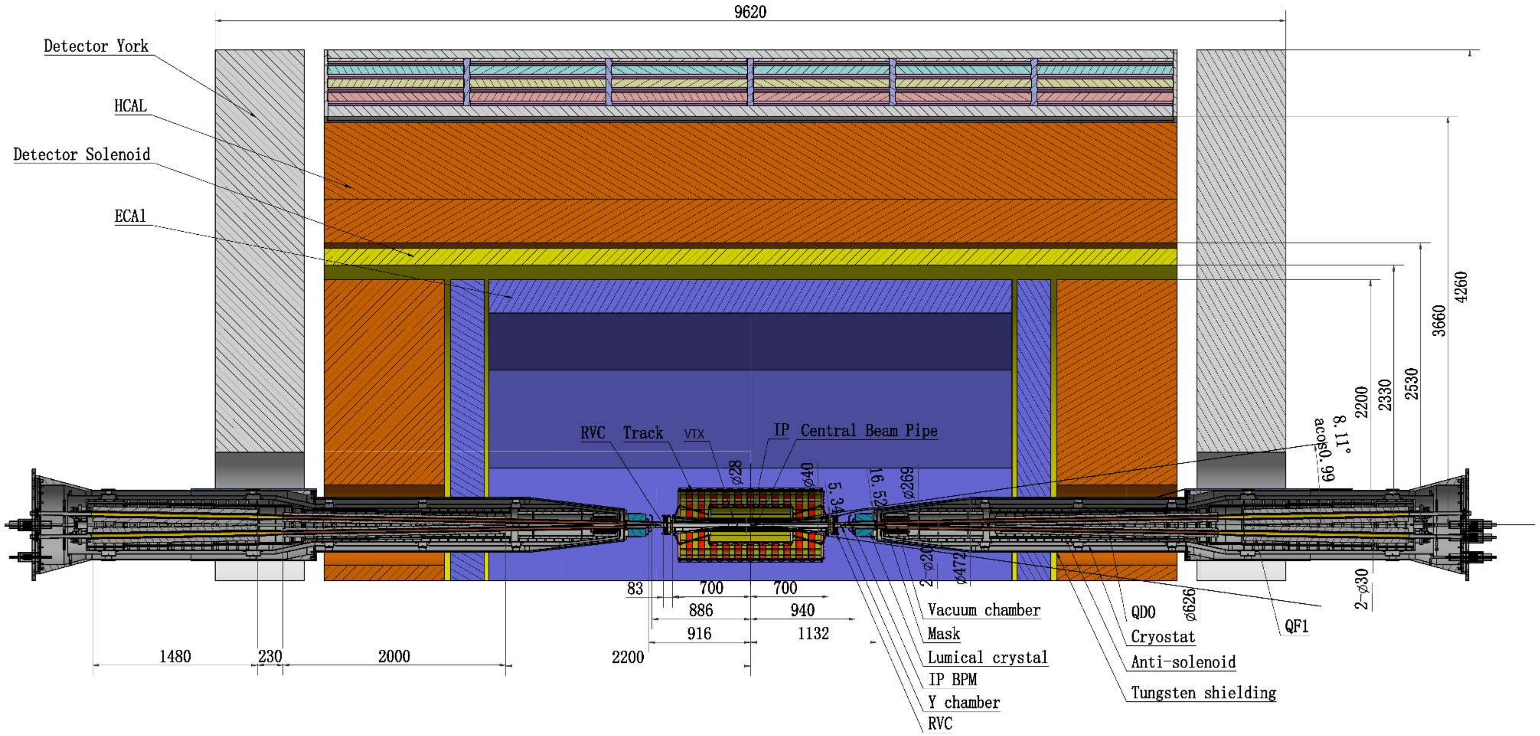
Outline

- **Introduction**
- **IR beam pipe structure**
- **Background estimation**
- **Mitigation design efforts**
  - Masks
  - Collimators
  - Shielding
- **Thermal Analysis**
  - HOM heating
  - Synchrotron radiation
  - Beam loss backgrounds
  - Beam pipe thermal analysis
- **Mechanical Design and Optimization**
  - Remote vacuum connector
  - SC magnet supports
- **Detector simulation**
- **Summary**

MDI layout and IR design

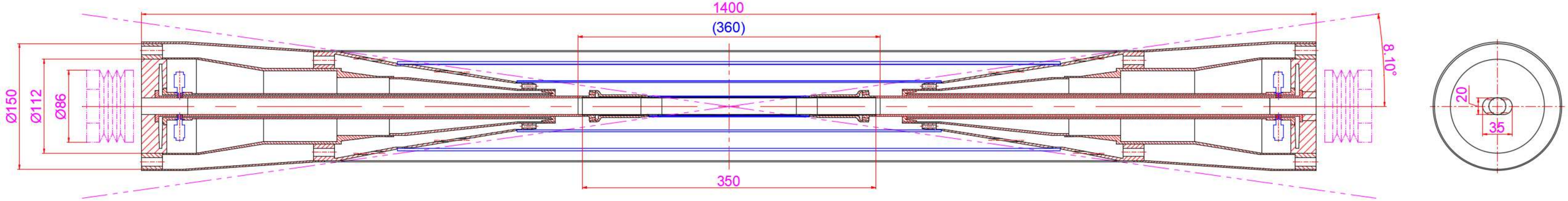


- The Machine Detector Interface (MDI) of CEPC double ring scheme is about ±7m long from the IP.
- The CEPC detector superconducting solenoid with 3T magnetic field （2T in Z） and the length of 7.3m.
- The accelerator components inside the detector without shielding are within a conical space with an opening angle of cosθ=0.993. Detective angle: acos0.99
- The e+e- beams collide at the IP with a horizontal angle of 33mrad and the final focusing length is to 1.9m.

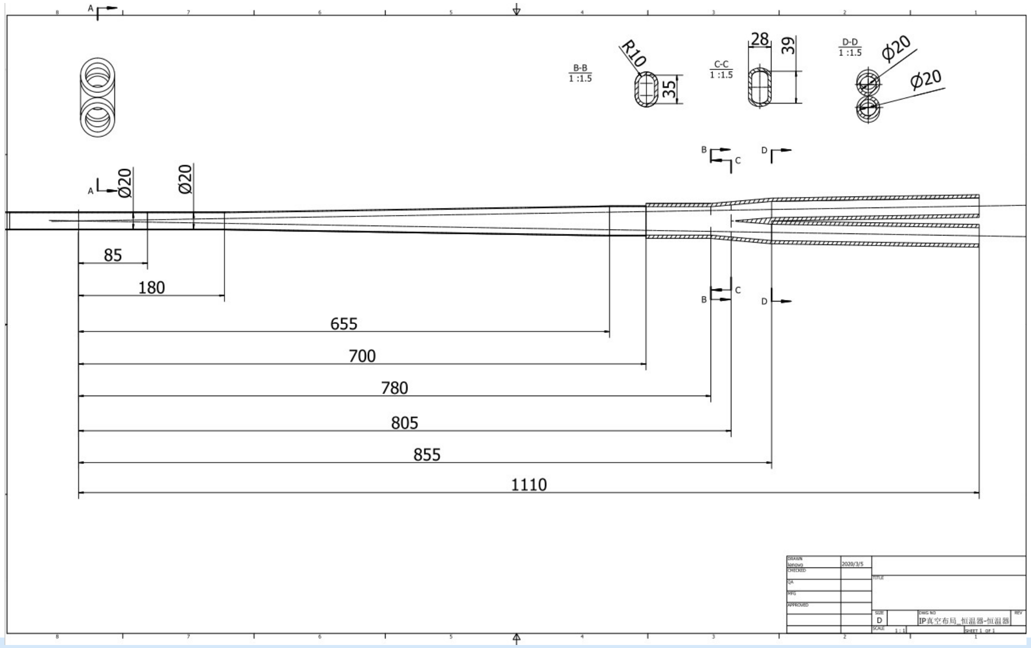
MDI parameters

	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*	0~1.9m				1.9m								
Crossing angle	33mrad												
MDI length	±7m												
Detector requirement of accelerator components in opening angle	8.11°												
QDa/QDb		3.2/2.8T	141/84.7T/m		1.21m	15.2/17.9mm	62.71/105.28mm	48mm	59mm	724.7/663.1keV	396.3/263keV	212.2/239.23W	99.9/42.8W
QF1		3.3T	94.8T/m		1.5m	24.14mm	155.11mm	56mm	69mm	675.2keV	499.4keV	472.9W	135.1W
Lumical	0.95~1.11m				0.16m			57mm	200mm				
Anti-solenoid before QD0		8.2T			1.1m			120mm	390mm				
Anti-solenoid QD0		3T			2.5m			120mm	390mm				
Anti-solenoid QF1		3T			1.5m			120mm	390mm				
Beryllium pipe					±120mm			28mm					
Last B upstream	64.97~153.5m			0.77mrad	88.5m					33.3keV			
First B downstream	44.4~102m			1.17mrad	57.6m					77.9keV			
Beampipe within QDa/QDb					1.21m							1.19/1.31W	
Beampipe within QF1					1.5m							2.39W	
Beampipe between QD0/QF1					0.3m							26.5W	

The new central beampipe design



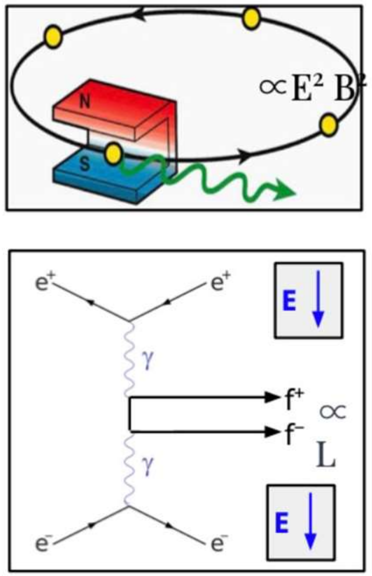
From IP(mm)	Shape	Inner diameter(mm)	Material	Marker
0-85	Circular	20	Be	
85~180	Circular	20	Al	
180~655	Cone	20~35	Al	Taper: 1:70
655~700	Circular	35	Al	
700~780	Circular	35	Cu	
780~805	Cone	35~39	Cu	
805~855	Race-track	39~20 double pipe	Cu	



- Crotch point at 805mm，with slope，breeches pipe starting point at 855mm，cone，interface point at 700mm

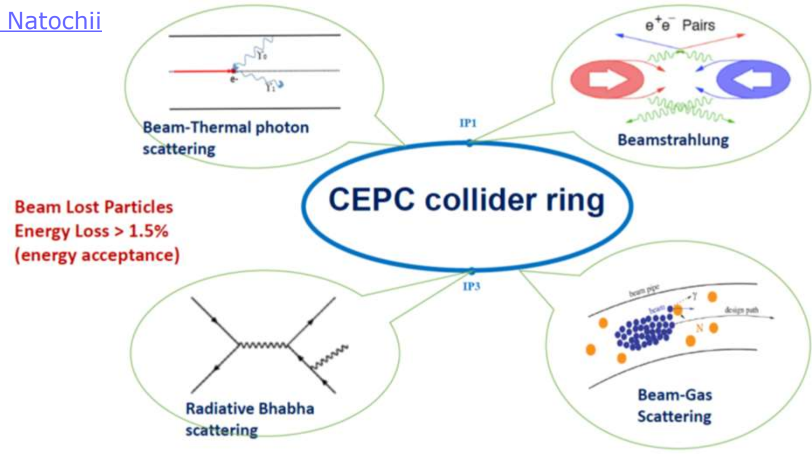
Background estimation

- Background sources
  - Photon backgrounds: SR, Pair production
  - Beam loss backgrounds
    - Radiative Bhabha scattering
    - Beam Gas scattering
    - Beam Thermal photon scattering
  - Injection background
- Real beam
  - Errors
  - Beam-beam effect
  - Beam tail
  - Solenoid
- Multi-turn tracking
  - Using built-in LOSSMAP with one step ahead output
  - SR emitting on
  - RF on
  - Radtapper on

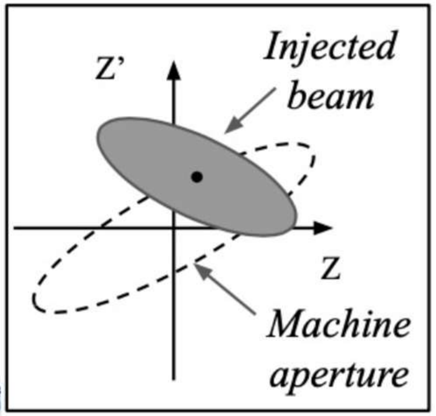


A. Natochii

Photon BG



Beam loss BG

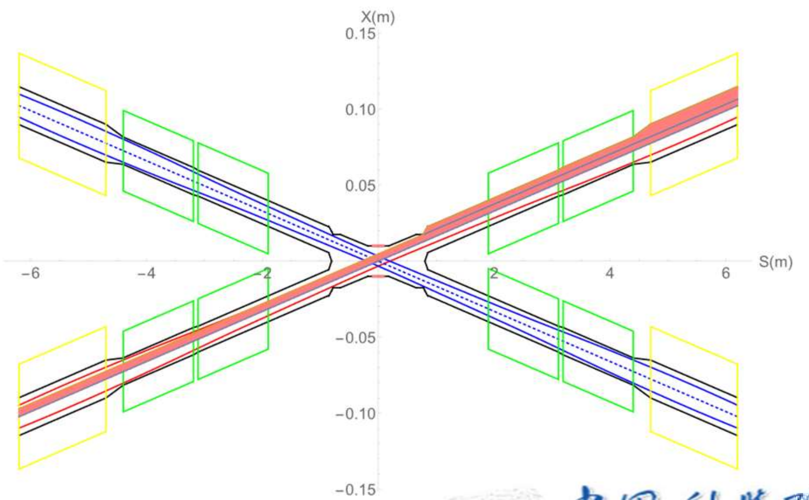


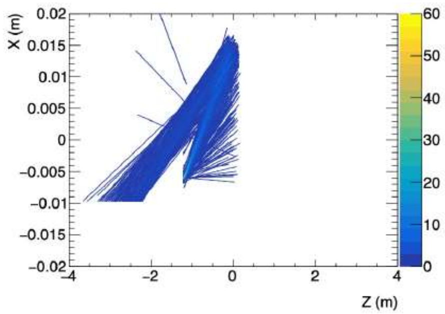
A. Natochii

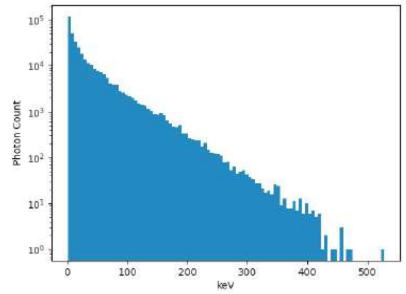
Injection BG

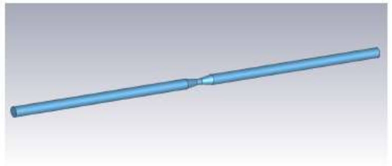
Synchrotron radiation

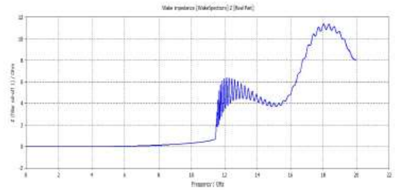
- No SR photons hitting the central beam pipe directly in normal conditions, which is generated from the last bending magnet in the upstream of IP
- However, some secondaries generated within the beam pipe of QD would hit the detector beampipe, even the beryllium part. Therefore, the mitigation methods must be studied.
- SR photons generated from the FD magnets 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.











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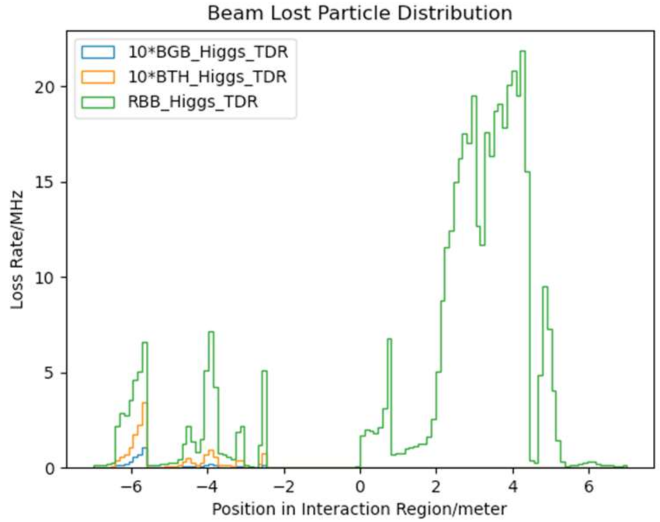
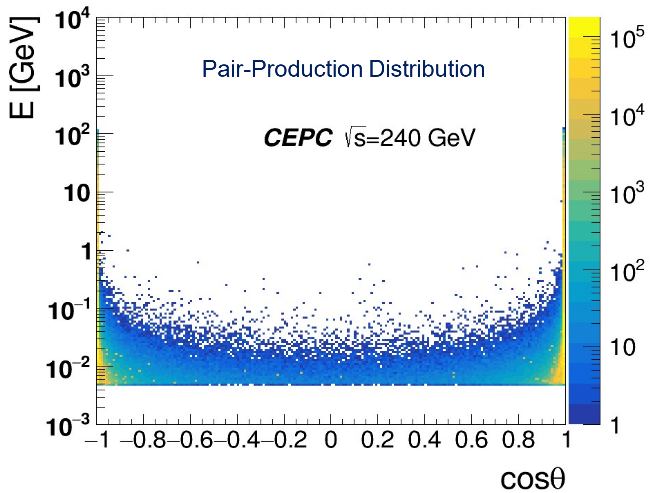
Radiation background

- Including Radiative Bhabha scattering, Beam-Gas scattering, Beam Thermal Photon scattering.
- Beam loss background from Beamstrahlung almost no in upstream IP, but mainly from pair-production distribution.

name	Position	Distance to IP/m	Beta function/m	Horizontal Dispersion/m	Phase	BSC/2/m	Range of half width allowed/mm
APTX1	D1I.785	44611	20.7	0.12	164.00	0.006	1~6
APTX2	D1I.788	44680	20.7	0.12	164.25	0.006	1~6
APTY1	D1I.791	44745	105.37	0.12	165.18	0.0036	0.156~3.6
APTY2	D1I.794	44817	113.83	0.12	165.43	0.0036	0.156~3.6
APTX3	D1O.5	1729.66	20.7	0.06	6.85	0.00182	1~6
APTX4	D1O.8	1798.24	20.7	0.12	7.10	0.00182	1~6
APTY3	D1O.10	1832.52	20.7	0.25	7.22	0.00182	0.069~3.3
APTY4	D1O.14	1901.1	20.7	0.25	7.47	0.00182	0.069~3.3
APTX5	DMBV01IRU0	56.3	196.59	0	362.86	0.01178	2.9~11.78

- ✓ Beam loss particle distribution with collimator design.
- ✓ Collimator design meet requirements of beam-stay-clear region, impedance, phase etc on.
- ✓ 4 sets of collimators were implemented per IP per Ring(16 in total)
  - ✓ 2 sets are horizontal(4mm radius), 2 sets are vertical(3mm radius).
- ✓ One more upstream horizontal collimator sets were implemented to mitigate the Beam-Gas background





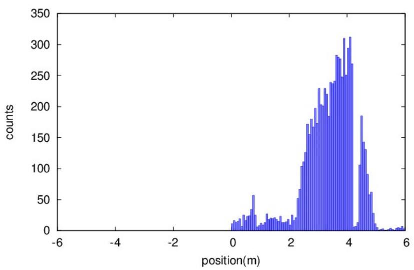
Injection background

- RBB is taken into account in all cases
- A simplified model of top-up injection beam
- Tails from imperfectly corrected X-Y coupling after the injection point
- some tolerances to imperfect beams from the booster (e.g. too large emittances)
- non-Gaussian distributions existing/building up in the booster and being injected into the main rings

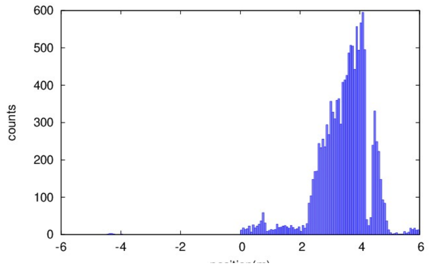
Injection beam parameters

Mode	tt	Higgs	W	Z
Bunch Number	37	240	1230	3840
Bunch Charge	0.96 nC	0.7 nC	0.73 nC	0.8 nC
Beam Current(mA)	0.11 mA	0.51 mA	2.69mA	9.2 mA
Beta_func (x/y)	200/55	200/55	200/55	200/55
Emittance (nm)	2.83	1.26	0.56	0.19
Bunch Length (mm)	2.0	2.0	1.7	0.96

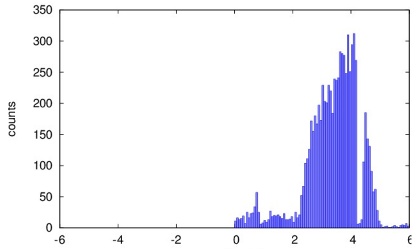
Circular beam



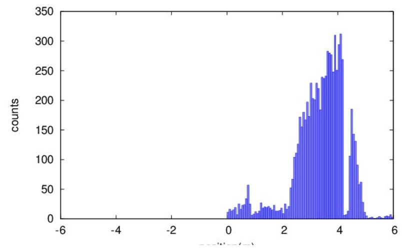
Injection beam



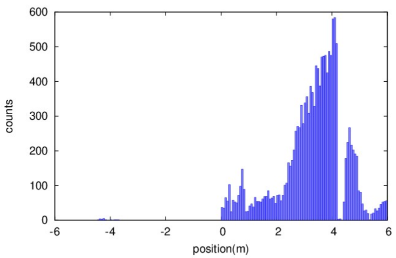
Gaussian beam with 3sigma



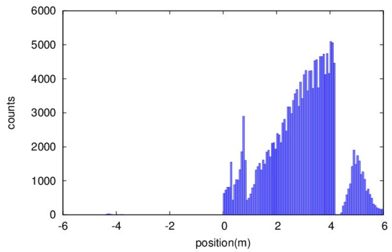
Gaussian beam with 40sigma



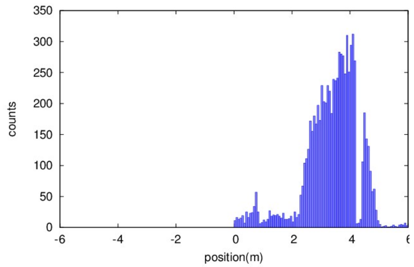
Large emittance ~10times



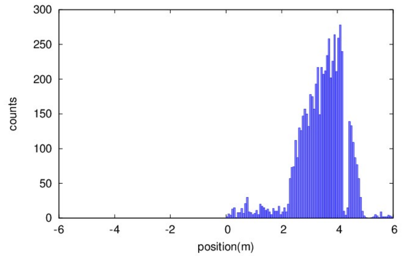
Large emittance ~1000times



Double gaussian beam

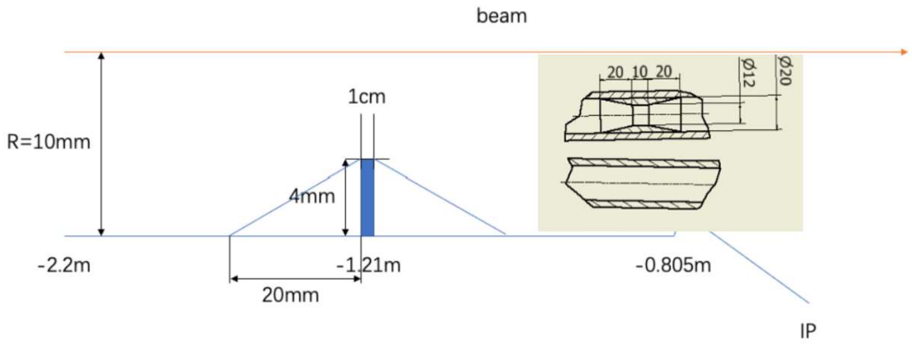


Uniform beam



- Almost no beam loss background in the upstream of the IP, while significantly increased downstream
- The existed collimation system can well cope
- No effect on the inner layer detector but may damage the outer layer or the endcap detector
- BG downstream may damage the SC magnet coils and cause quench.
- Tungsten shielding demanded in the IR.
- Since the very tight space in the IP region, a tungsten-alloy beam pipe is under design in the CEPC TDR stage.

SR mitigation – mask and Au shielding



- Masks design(two masks/IP/ring) :
  - Tungsten
  - One locates at -1.21m with 4mm height and 10mm long
  - The other at -4.2m with 0.6mm height
- Lots of photons are secondaries, generated within QD0

Methods	Photon hitting number on Be/BX	Deposition power on Be(W)
No mask	39400.0	30.57*e-5
1.21-mask-Cu	1736.0	1.45*e-5
1.21-mask-W	1698.0	1.36*e-5
2.2-mask-Cu	1147.0	0.94*e-5
1.21-mask-Cu-5μmAu	216.0	0.273*e-5

- Photons hitting number on Be/BX reduced by two orders of magnitude
- ~216 photons/BX could hit Be
  - ~2.73x10^{-6} W deposition power on Be beampipe

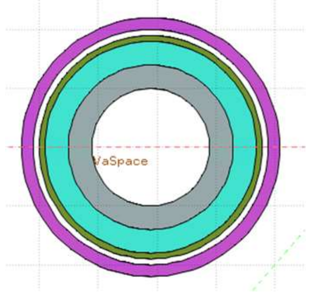
Shielding

- Beam loss in the downstream IR with a large amount, due to the process of radiative bhabha scattering, beamstrahlung, beam-gas scattering, beam thermal photon scattering.
- Radiation dose may damage the SC magnet coil and the detector.

solution

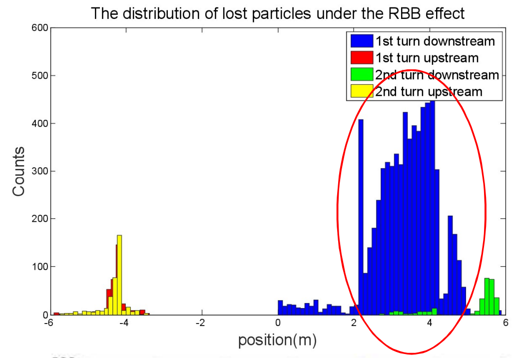
1. Tungsten IR beam pipe,
2. Combined iron and tungsten yoke of SC magnet

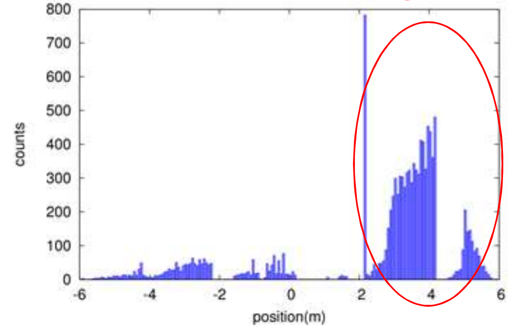
Key Issues on Calculation and Simplification of Beam pipe model

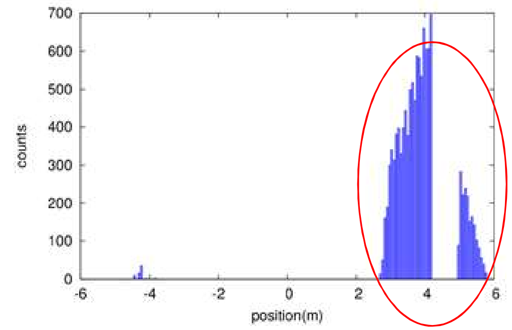


- Pure tungsten IR beam pipe with 4mm thickness without cooling taken into account, simulate the Absorbed Dose on Coil (Region)
- Only Beam-Gas beam loss is taken into account until now
- Take the loss rate calculated by SAD into account:
  - ~0.00166 Gy/s(0.166rad/s)
  - ~14.35 Gy/day
  - ~36662.49 Gy/lifetime(Higgs plans to run 7 years)
  - Limit is 100000 Gy/lifetime

White: Vacuum
Gray: Tungsten Pipe
Light Green: Helium
Heavy Green: Stainless Steel Vassel
Pink: Coil

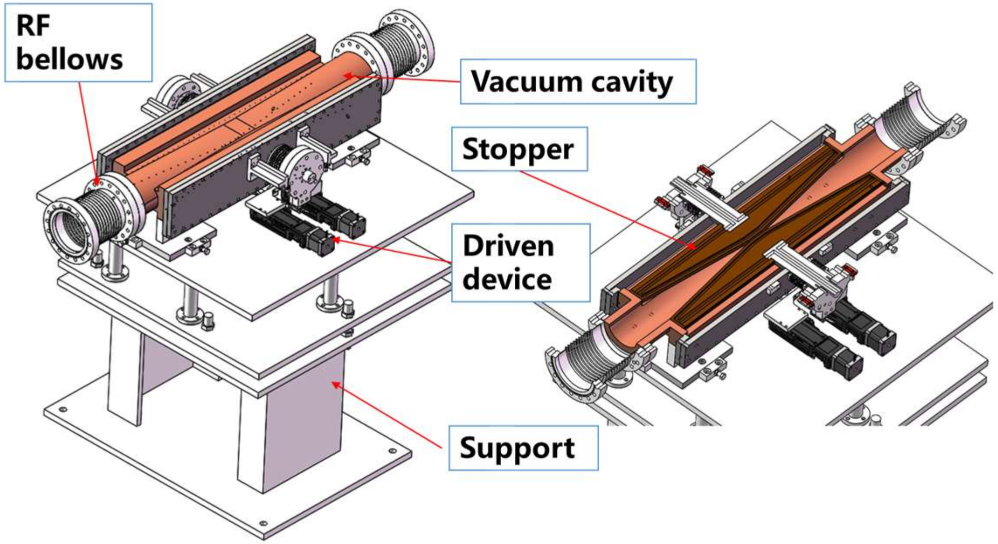




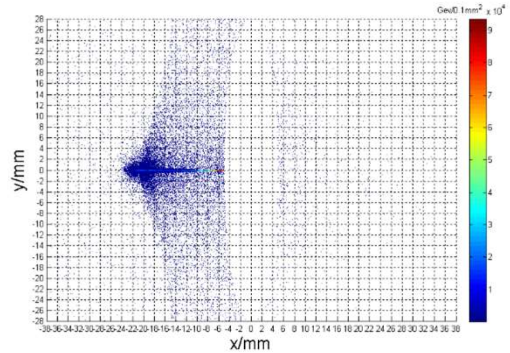


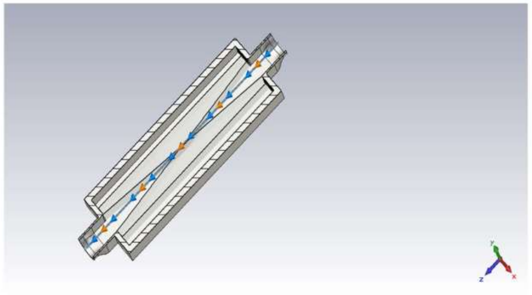
Movable collimators

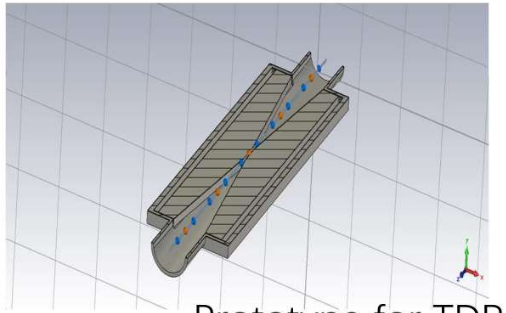
- Located in straight section between two dipoles, the length is 800 mm.
- SR power: 9.3kW @Higgs, 30MW



Particle deposition:
- ✓ Jaw material: Cu
- ✓ Total heat generation: 91.6 W
- ✓ Maximum temperature raise by particle-material reaction: 2℃

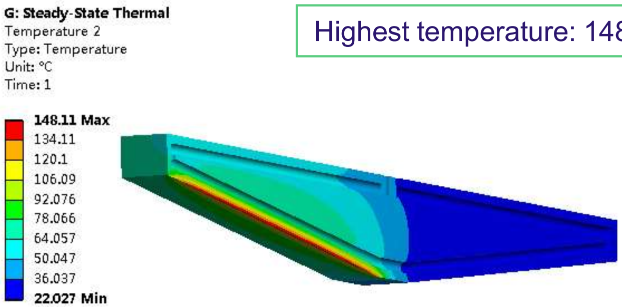


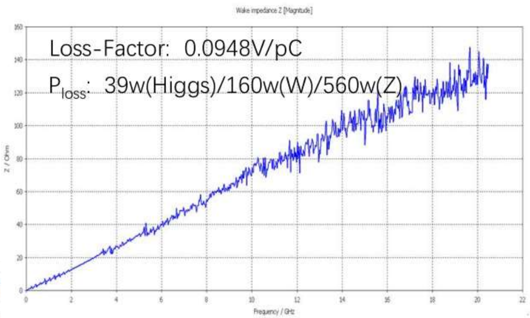


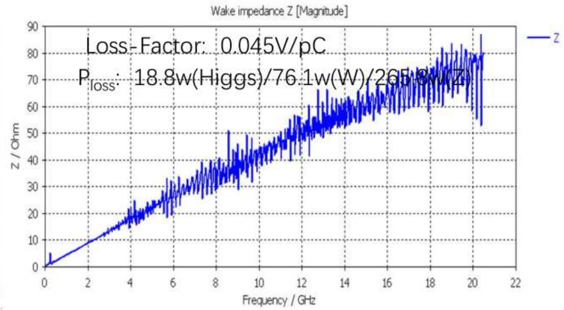


Prototype for TDR

Highest temperature: 148 ℃

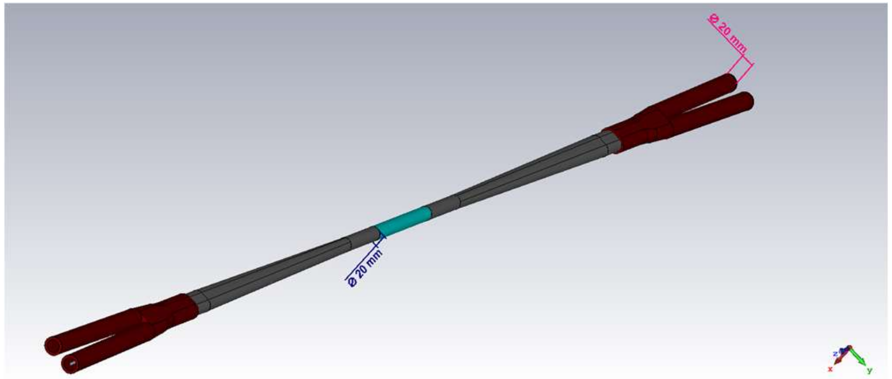




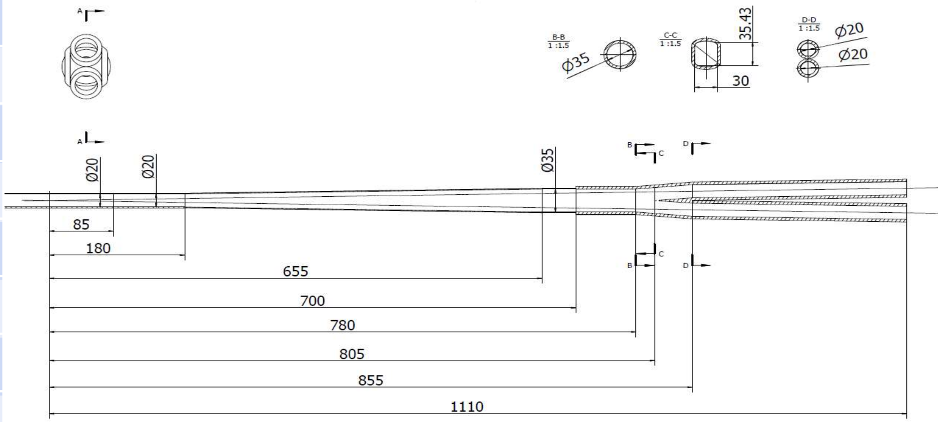


HOM power distribution

- results for MDI 20mm-20mm
- Transition region: Racetrack (including materials)
- σ_z=5mm: Two beam in the IR
- Loss factor Trap in IR @k_trap: 0.032v/pc
- P_{trap}: H/W/Z/tt: 24.0w/117.1w/1160.8w/6.67w

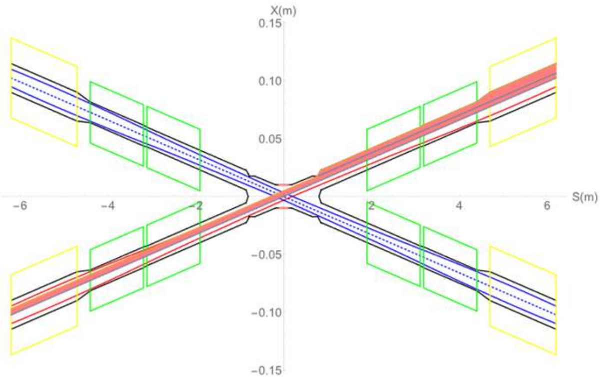


Position	Position Start-end (mm)	material	Length (mm)	Higgs(w) & (w/cm^2)	W (w) & (w/cm^2)	Z(w) & (w/cm^2)	ttbar (w) & (w/cm^2)
Be pipe (w)	0-85	Be	85	1.13 & 0.021	5.587 & 0.105	55.295 & 1.35	0.31 & 0.005
Be pipe transition(w)	85-180	Al	95	0.61 & 0.01	2.950 & 0.049	29.280 & 0.491	0.172 & 0.007
Transition pipe (w)	180-655	Al	475	6.99 & 0.017	34.48 & 0.085	341.562 & 0.83	1.958 & 0.005
Transition (w)	655-700	Al	45	0.62 & 0.015	2.95 & 0.071	29.28 & 0.701	0.172 & 0.004
RVC bellow (w)	700-780	Cu	80	0.52 & 0.007	2.532 & 0.034	25.002 & 0.337	0.14 & 0.002
Transition on Y-crotch	780-805	Cu	25	0.16 & 0.007	0.785 & 0.032	7.822 & 0.316	0.05 & 0.002
Y- crotch (w)	805-855	Cu	50	0.33 & 0.005	1.572 & 0.024	15.626 & 0.241	0.091 & 0.002
Quadrupole pipe(w)	855-1100	Cu	245	1.58 & 0.005	7.735 & 0.024	75.594& 0.24	0.434 & 0.002
Total	0-1100	-	1100	12.0 &0.011	58.594 &0.056	580.46 & 0.56	3.331 & 0.003



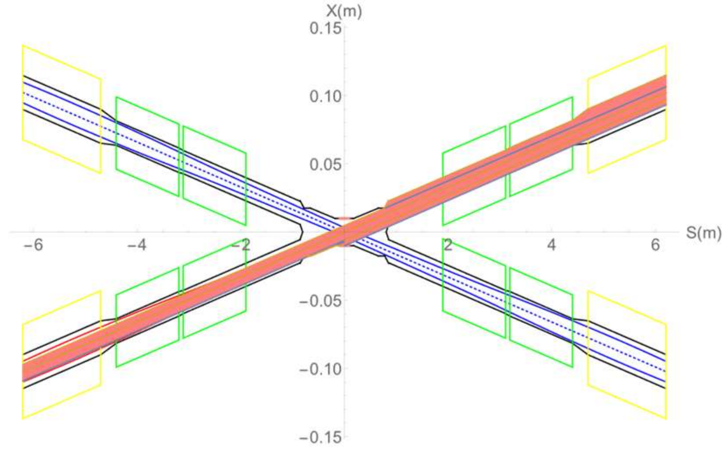
Heat load from SR

- In normal conditions, there is no SR photons hitting the central beam pipe.
- Single layer beam pipe with water cooling, SR heat load is not a problem.



Region	SR heat load	SR average power density
0~780mm	0	0
780mm~805mm	23.04W	256W/cm^2
805mm~855mm	53.39W	296.6W/cm^2
855mm~1.9m(QDa entrance)	4.32W	1.15W/cm^2
QDa	3.28W	0.75W/cm^2
QDa~QDb	22.92W	79.58W/cm^2
QDb	3.96W	0.91W/cm^2
QDb~QF1	71.04W	65.8W/cm^2
QF1	7.26W	1.34W/cm^2

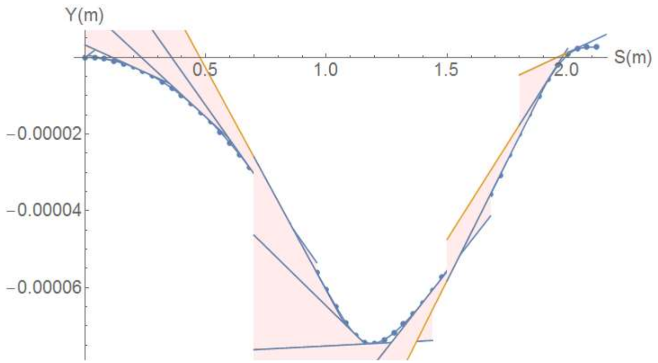
- In abnormal conditions, SR photons hitting the bellows (no cooling) and berrylium pipe under the extreme beam conditions , since it is a transient effect, heat load is not a problem.



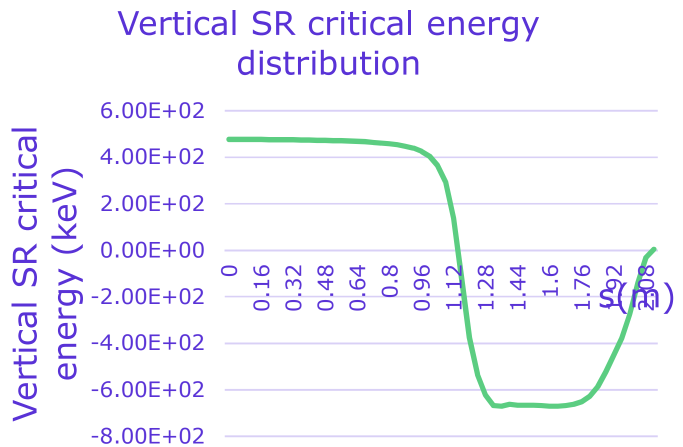
- In extreme cases ~ at least 10 times per day. The beam will be stopped within 0.5ms when abnormal.
- The background of the detector and radiation dose should be considered under abnormal conditions.

SR from solenoid combined field

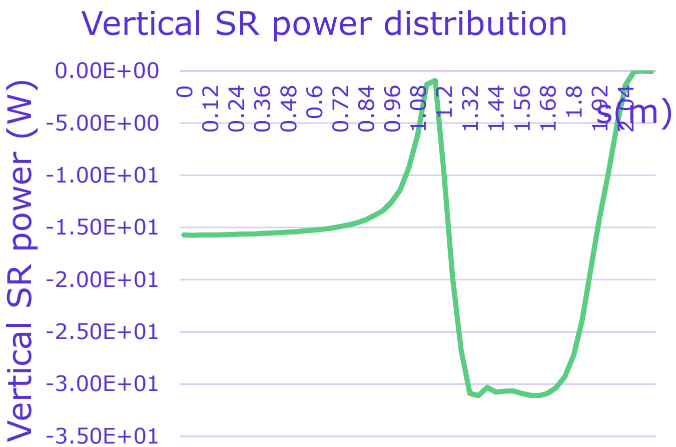
- Horizontal trajectory will couple to the vertical
- Due to the sol+anti-sol field strength quite high, maximum~4.24T, transverse magnetic field component is quite high.
- SR from vertical trajectory in sol+anti-sol combined field should be taken into account.



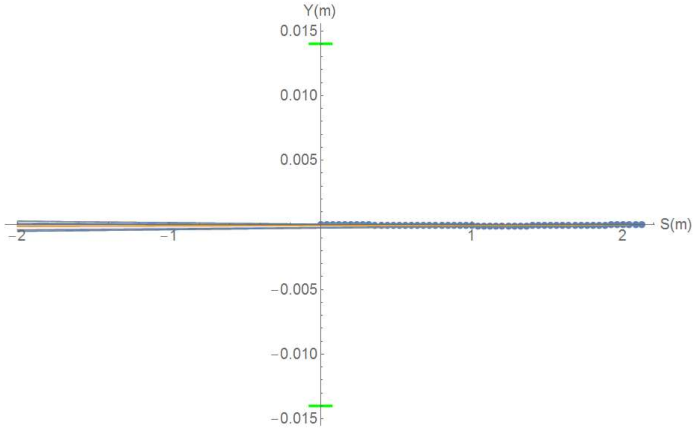
- SR fan is focused in a very narrow angle from -116urad to 131urad
- SR will not hit Berryllium pipe, and no background to detector.
- SR will hit the beam pipe ~213.5m downstream from IP
- Water cooling is needed.



Maximum: 670keV



Maximum: 31W



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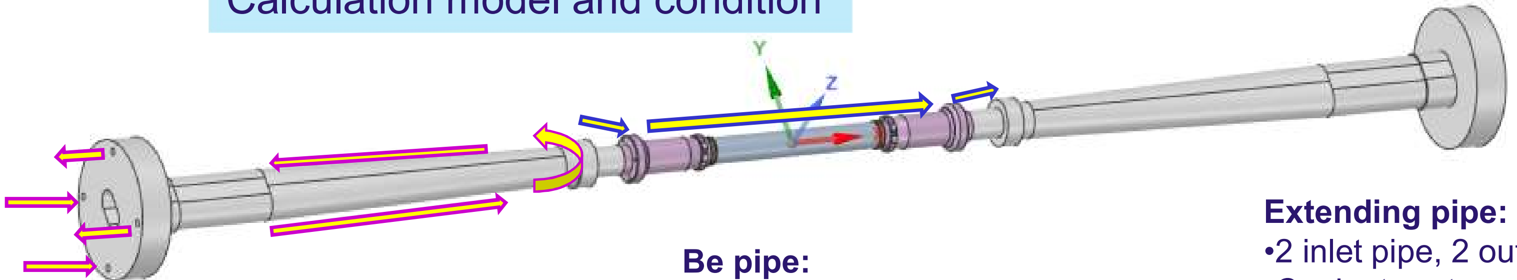
Heat load in IR from beam loss background

Region	RBB	Beamstrahlung	Beam-Gas	BTH
Berryllium pipe	6.7mW	0	0	0
Detector beam pipe	0.024W	0	4.8uW	1.2uW
Accelerator beam pipe before QDa	0.17W	0	4.2uW	1.2uW
QDa~QDb	2.13W	3.8uW	5.9uW	1.8uW
QDb~QF1	0.01W	3.8uW	0.5uW	0.6uW
QF1	0.26mW	0	3.7uW	0.66uW

- Beam loss particles from the process of radiative Bhabha scattering, Beamstrahlung, Beam-Gas scattering, and beam-thermal photon scattering hitting the IR beam pipe
- Heat load in IR from beam loss background is so small, compared to synchrotron radiation and HOM.
- The photons generated from the process of radiative Bhabha scattering, Beamstrahlung, and Beam-Gas scattering with small angle and large energy, still under analysis.

Beam pipe thermal analysis

Calculation model and condition



Extending pipe:
- 2 inlet pipe, 2 outlet pipe
- Coolant: water
- Inlet temperature: 20℃
- Inlet velocity: 0.5m/s（1.7L/min）

Be pipe:
- 4 inlet pipe, 4 outlet pipe
- Coolant: paraffin
- Inlet temperature: 20℃
- Inlet velocity: 0.5m/s（0.8L/min）

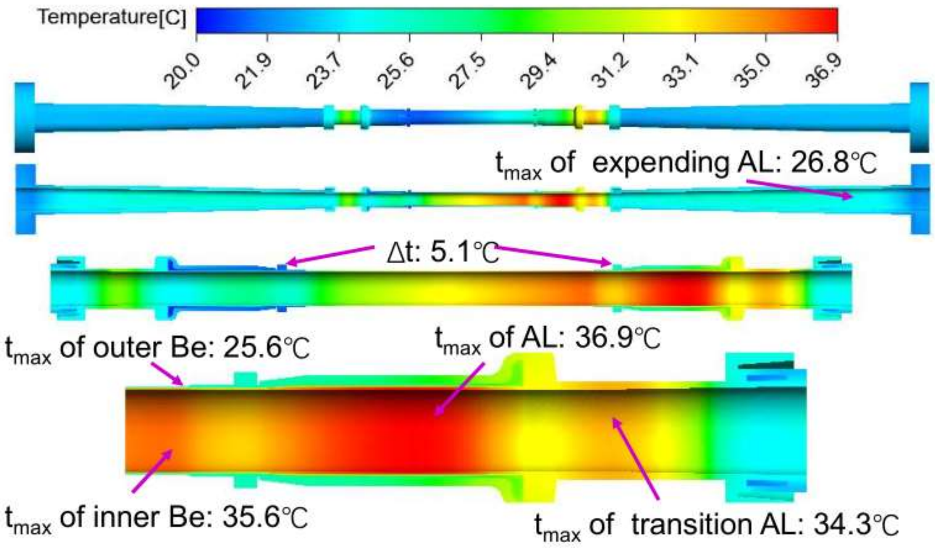
Extending pipe:
- 2 inlet pipe, 2 outlet pipe
- Coolant: water
- Inlet temperature: 20℃
- Inlet velocity: 0.5m/s（1.7L/min）

Heat source distribution

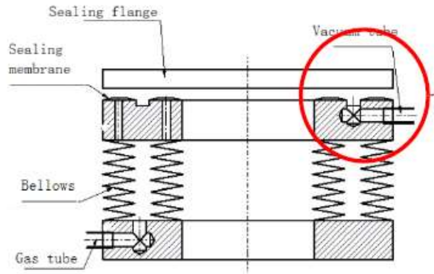
Position	Z(w) & (w/cm2)
Be pipe (w)	55.295 & 1.35
Be pipe transition(w)	29.280 & 0.491
Transition pipe (w)	341.562 & 0.83
Transition (w)	29.28 & 0.701

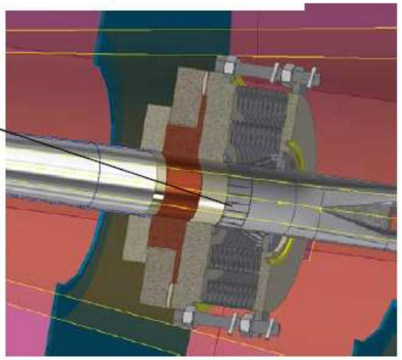
Calculation results:

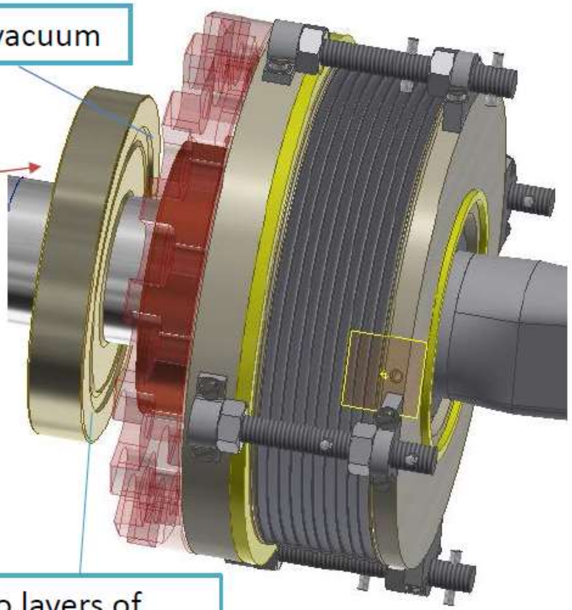
- ✓ Temperature difference ~5.1^{0}C between two sides of the first layer detector
- ✓ Temperature low, temperature difference small, meet the requirement



Remote vacuum connector



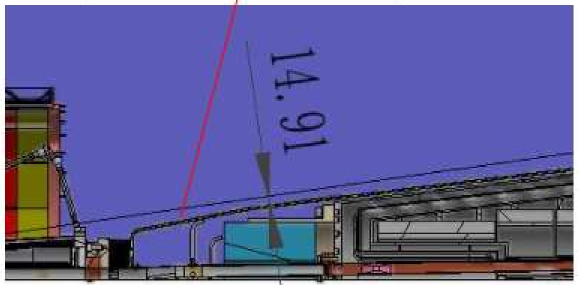




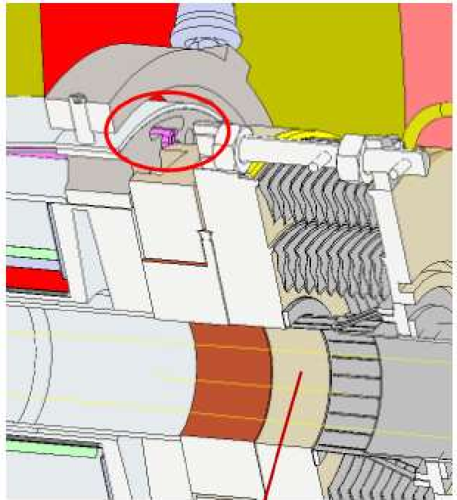
- Replace the sealing membranes by two layers of edge sealing.

Dimensions:

- Transversal: Max. φ174mm
- Longitudinal: ~83mm



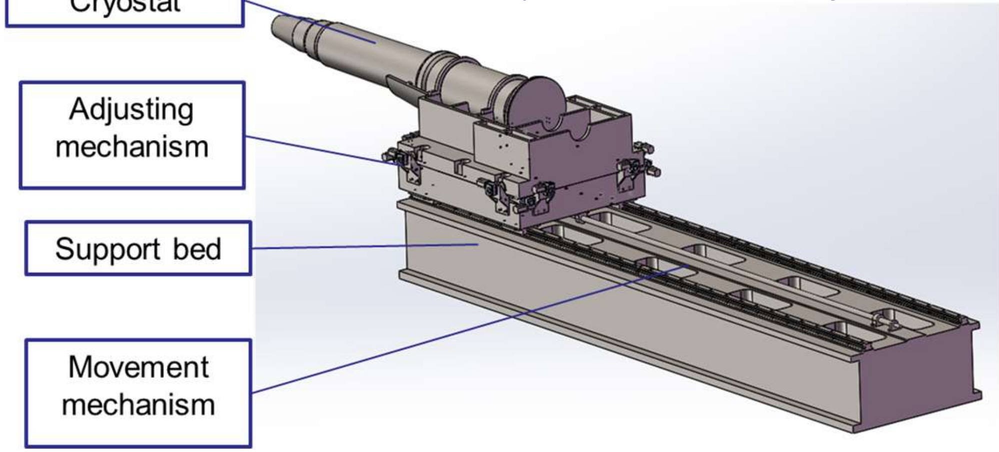
RVC distance to detective angle : 14.91mm (gas tube)

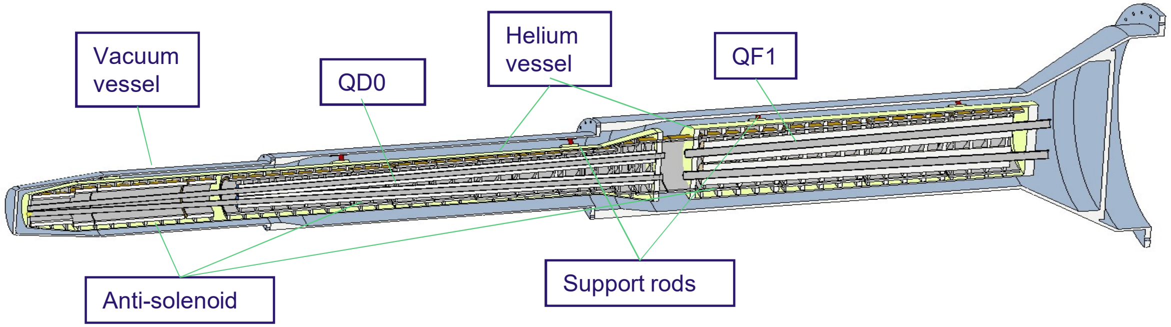


No interference for this design!

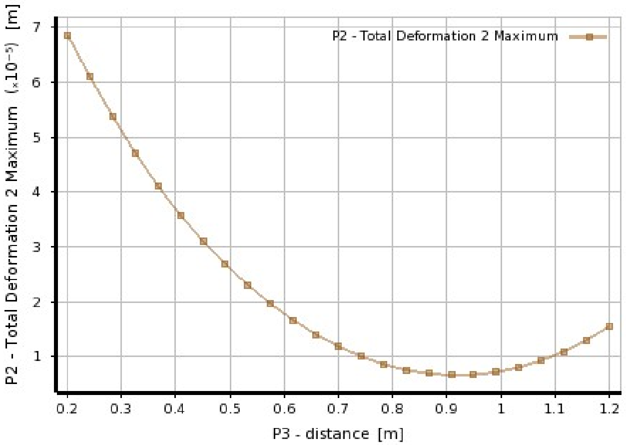
SC magnet supports

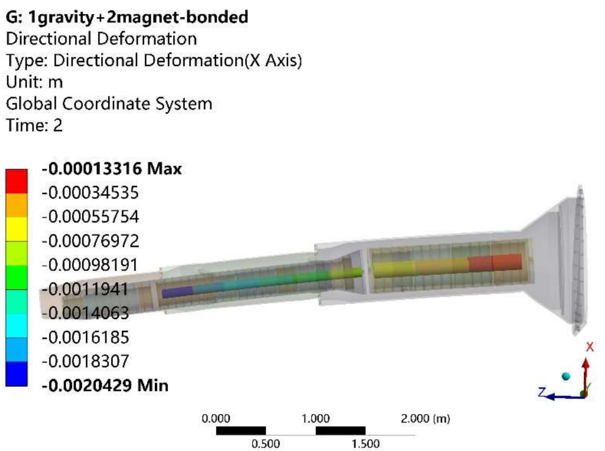
The cryostat is about 5.5 m long. The cantilever length is 3.6~5.5 m.





Magnet	Support	Optimized uneven deformation (um)
QD0	Skeleton	2.1
	Solid	3.2
QF1	skeleton	0.8



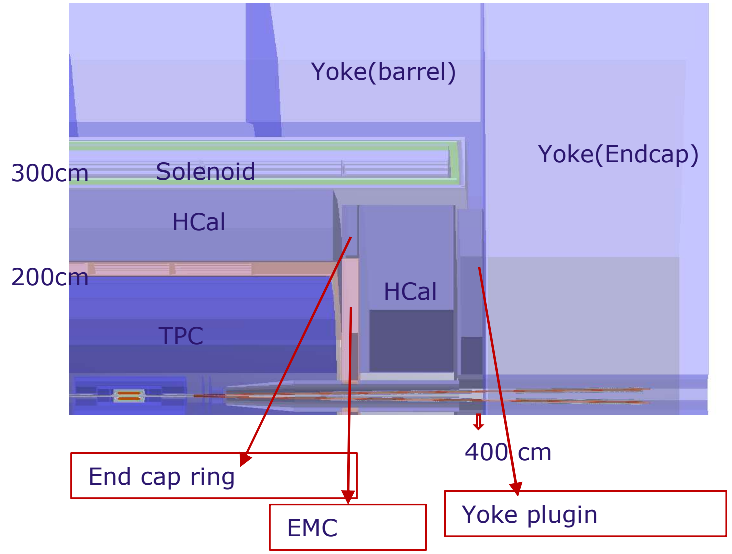


- The cryostat was 5 meters long with18 mm thick stainless wall. The maximum deformation was 190 um.
- The uneven deformation reduced significantly with structure optimization within the cryostat

Full Detector Simulation

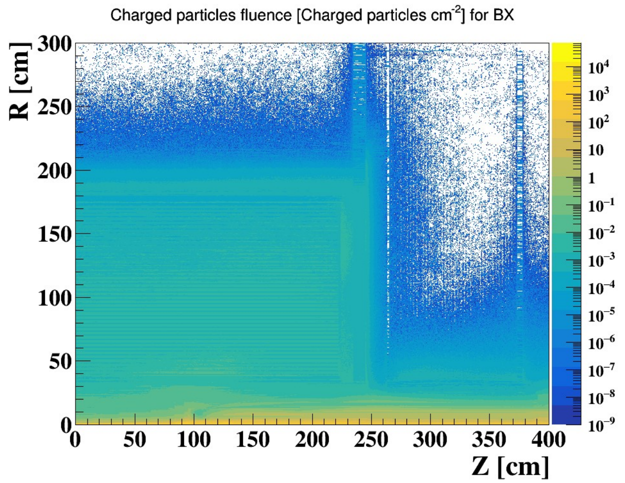
- **Two Main Concern has been taken for detector impacts:**
  - Detecting Efficiency(Occupancy): The ratio of Data/Noise
  - Detector Safety: Radiation Tolerance/Cooling Issues
- **Three quantities has been scored:**
  - Charged Particle Fluence(Hit Density)
  - Total Ionizing Dose(TID)
  - 1 MeV Silicon Equivalent Fluence(NIEL)
  - A Safety of 10 is always applied to all results

- Could reach Ecal and outside
- Characterized by Hit Density, TID and NIEL



Higgs ~ 50MW

	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)	NIEL($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)
Vertex	2.3	5360	120.4
TPC	2.59e-2	387.09	42.503
Ecal Barrel	1.16e-3	31.56	8.002
Ecal EndCup	1.36e-3	14.175	6.128
Hcal Barrel	2.78e-5	1.450	0.9326
Hcal EndCup	1.32e-3	26.31	6.351



Summary

- The MDI layout has been renewed. Compatible and no interference for the design.
- New Φ20mm IR beam pipe is designed and renewed.
- The estimation of the radiative background from photon background, beam loss background and injection background has been updated.
- The mitigation efforts of every kinds of background dedicated to the mask, collimator and shielding has been designed.
- The thermal analysis including HOM heating, synchrotron radiation, beam loss background and beam pipe thermal analysis meet the requirement.
- Some key devices such as remote vacuum connector and SC magnet supports are designed. The uneven deformation reduced significantly with structure optimization within the cryostat.
- The full detector simulation shows the impact on detector small enough.

Thanks