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HKUST JOCKEY CLUB INSTITUTE FOR ADVANCED STUDY

CEPC MDI Issues

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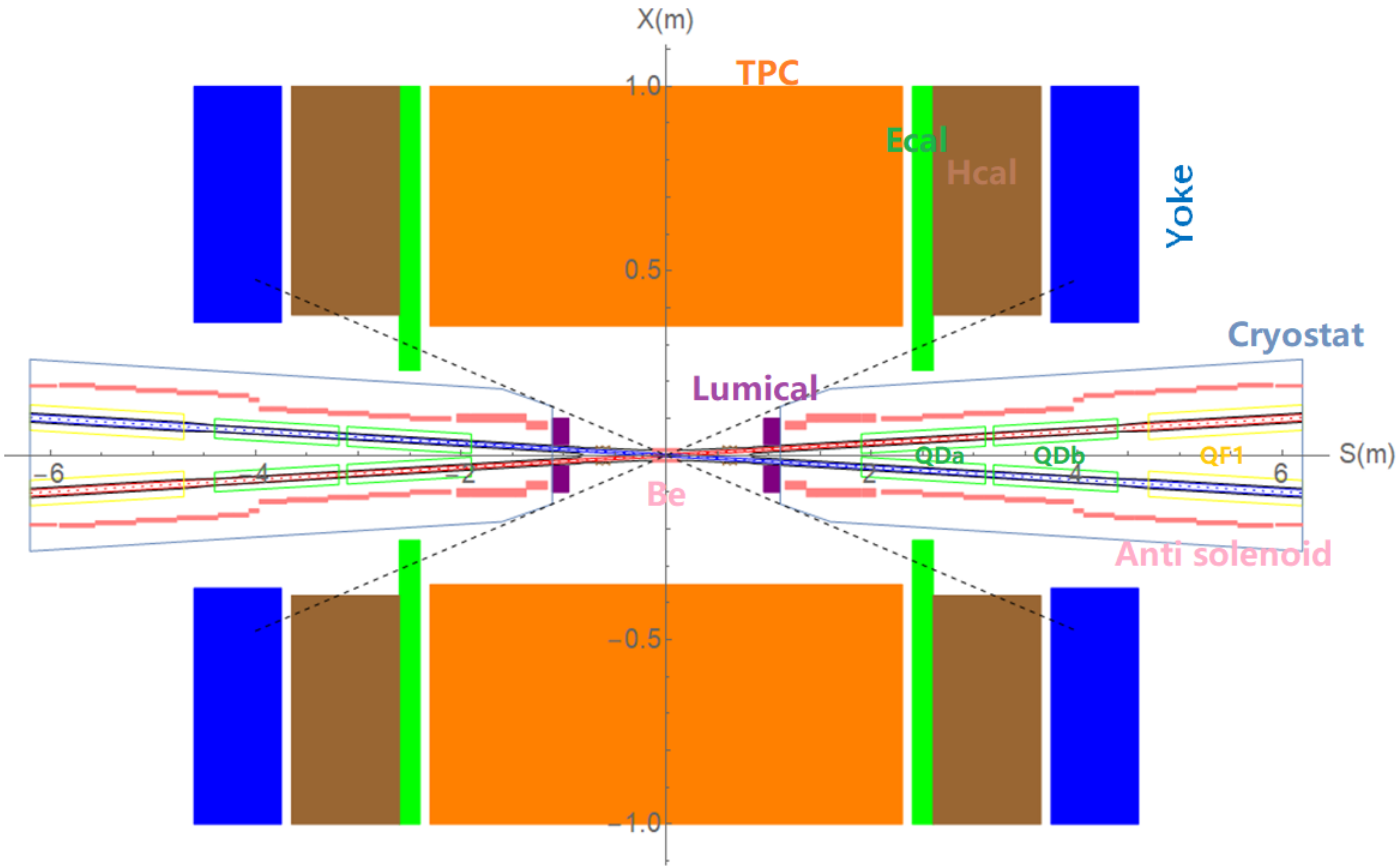
Outline

- MDI design for High Luminosity Higgs
- CDR → TDR optimization for MDI
- MDI mechanics and integration
- 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 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	141/84.7 T/m		1.21m	15.2/17.9mm	62.71/105.28mm	48mm	59mm	724.7/663.1 keV	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							1.19/1.31 W	
Beampipe within QF1					1.5m							2.39W	
Beampipe between QD0/QF1					0.3m							26.5W	

QDa/QDb, QF1 physics design parameters

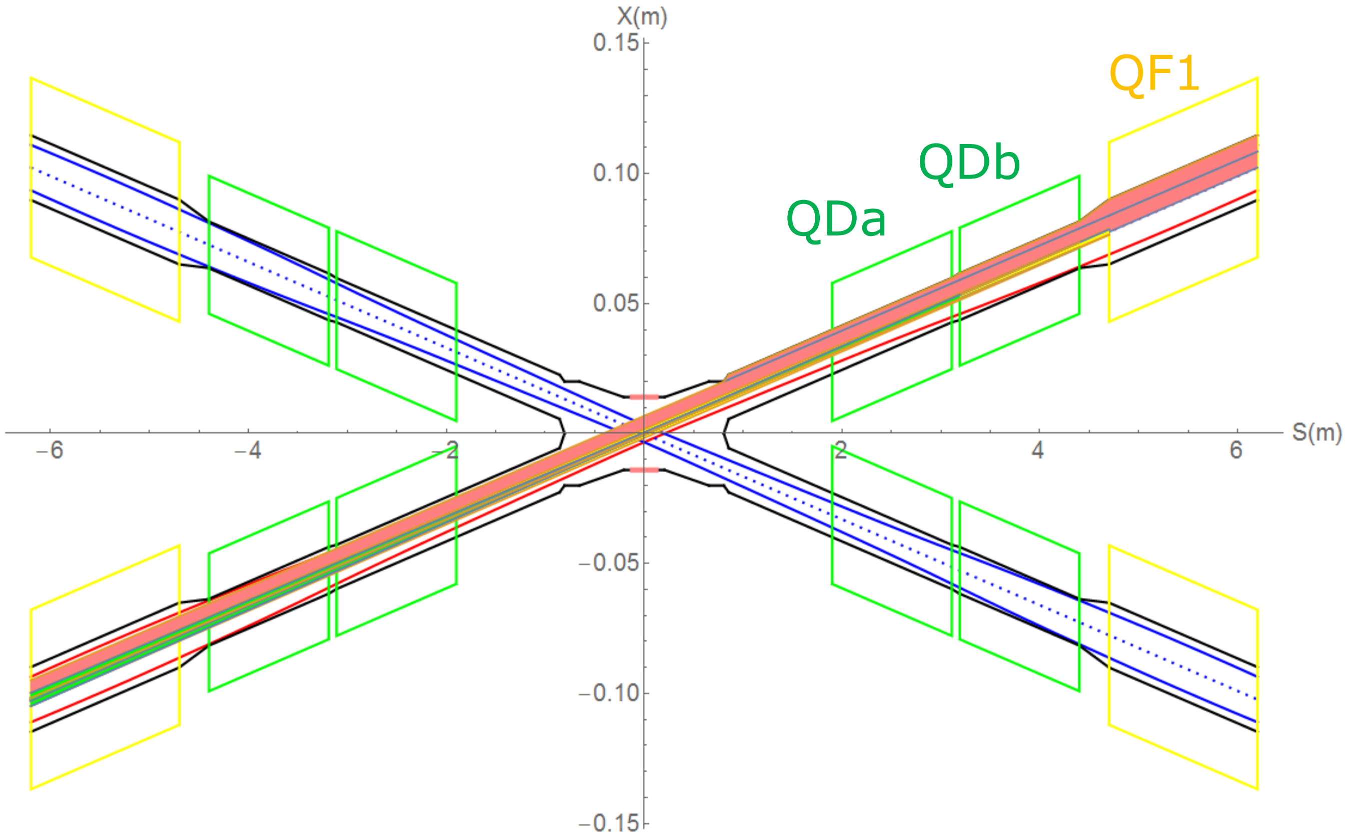
β_y*=1mm, β_x*=0.33m

QDa/QDb	Horizontal BSC 2（18σ_x+3）	Vertical BSC 2（22σ_y+3）	e+e- beam center distance
Entrance	9.15/12.41 mm	12.89/15.22 mm	62.71/105.28mm
Middle	10.37/14.84 mm	14.61/14.88 mm	82.84/125.41mm
Exit	12.13/17.92 mm	15.21/13.87 mm	102.64/145.21mm
Good field region	Horizontal 12.13/17.92 mm; Vertical 15.21/15.22 mm		
Effective length	1.21 m		
Distance from IP	1.9/3.19 m		
Gradient	141/84.7 T/m		

QF1	Horizontal BSC 2（18σ_x+3）	Vertical BSC 2（22σ_y+3）	e+e- beam center distance
Entrance	19.66 mm	13.21 mm	155.11 mm
Middle	23.02 mm	12.00 mm	179.87 mm
Exit	24.14 mm	11.60 mm	204.62 mm
Good field region	Horizontal 24.14 mm; Vertical 13.21 mm		
Effective length	1.5 m		
Distance from IP	4.7 m		
Gradient	94.8 T/m		

SR on IR beam pipe from last bend upstream and Final Doublet

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



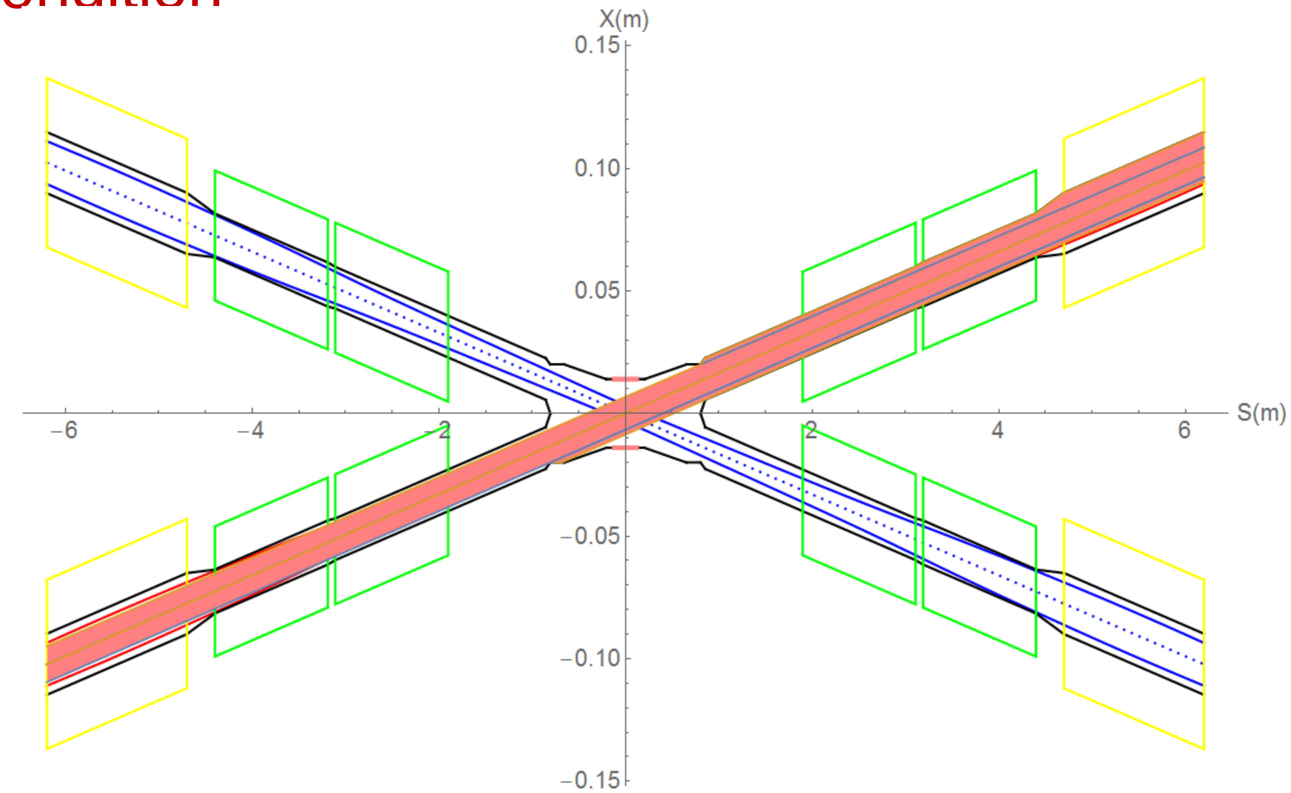
Region	SR heat load	SR average power density
0~805mm	0	0
805mm~855mm	12.5W	69.4W/cm^2
855mm~1.9m(QDa entrance)	1.06W	0.28W/cm^2
QDa	1.19W	0.27W/cm^2
QDa~QDb	3.73W	12.95W/cm^2
QDb	1.31W	0.3W/cm^2
QDb~QF1	26.5W	4.9W/cm^2
QF1	2.39W	0.44W/cm^2

SR from last bending magnet upstream of IP

Abnormal condition

- SR photons hitting the bellows under the extreme beam conditions, temperature rise ~1^0C

- **Extreme condition, eg, if a magnet power is lost, a large distortion will appear immediately for the whole ring orbit. The beam will be lost when exceeded.**
- **In extreme cases ~ at least 10 times per day. The beam will be stopped within 0.5ms when abnormal. It is not afraid of this 0.5ms for other material beam pipe except beryllium pipe.**
- **The background of the detector should not be considered under abnormal conditions.**
- **It is not necessary to care about whether the beam orbit deviation will affect detector operation, since the high background part will be removed when data analysis is carried out.**



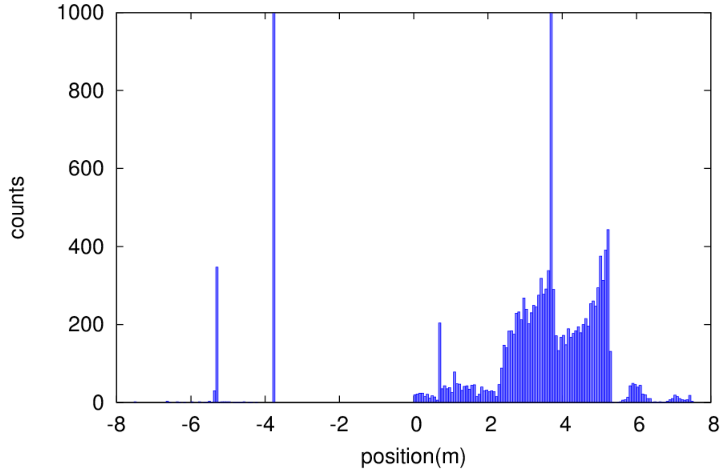
SR will enter into the bellows (no cooling):

- IP~677mm, no SR heat load.
- -677~-805mm beam pipe, SR power ~14.65W, APD~ 31.8W/cm^2.
- -805~855mm beam pipe, SR power~12.96W, APD~72W/cm^2.
- Temperature rise ~1^0C

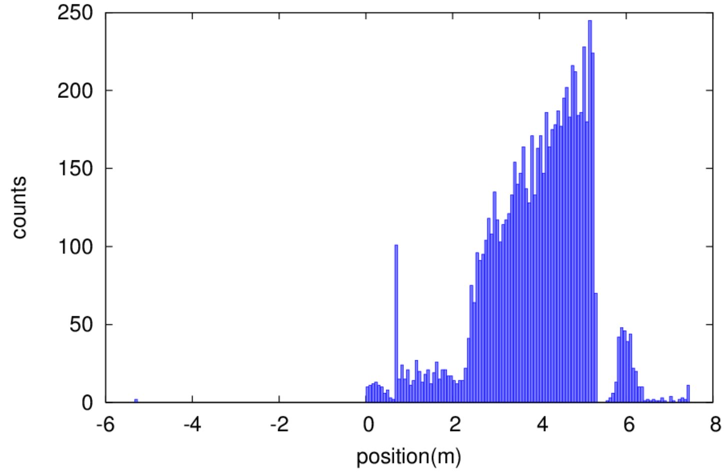
Beam loss from RBB and BS

Radiative Bhabha scattering

Without collimator

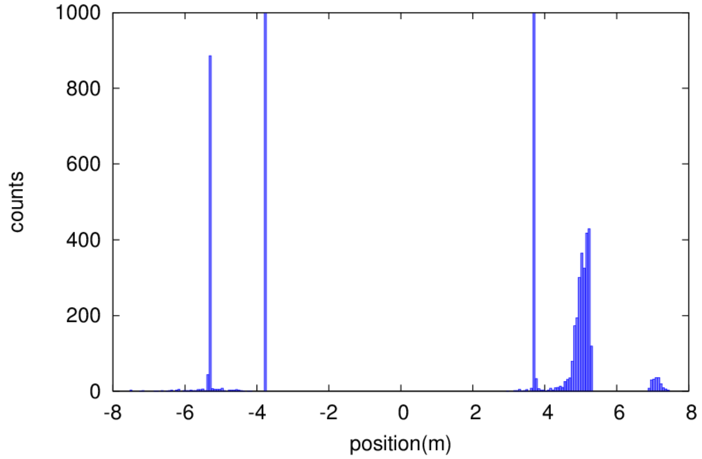


With collimator

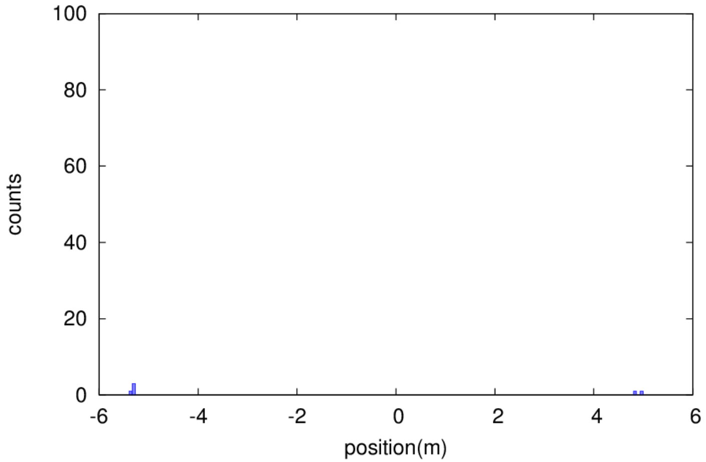


Beamstrahlung

Without collimator

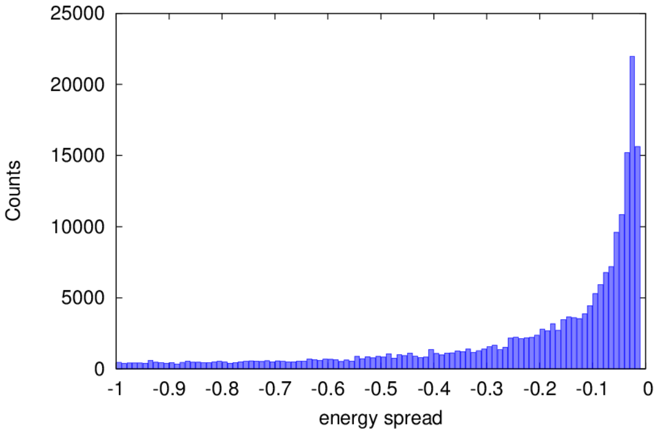


With collimator

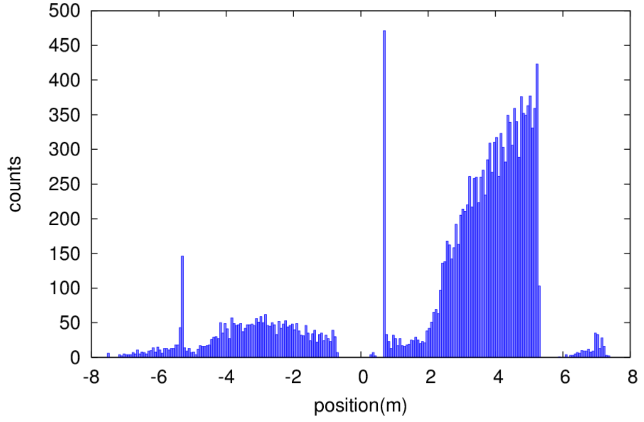


Beam loss from Beam-gas bremsstrahlung and Beam thermal photon scattering

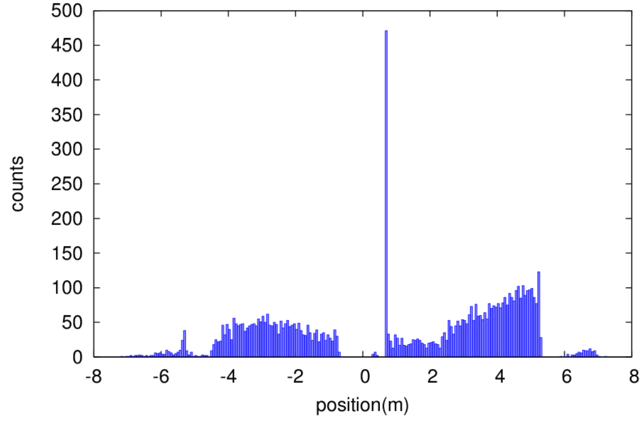
events



Without collimator

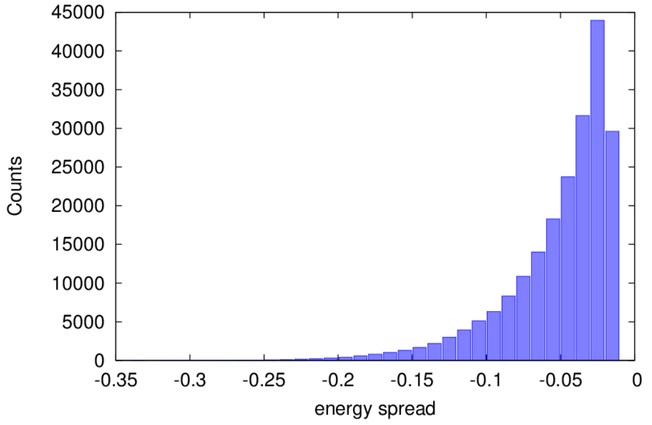


With collimator

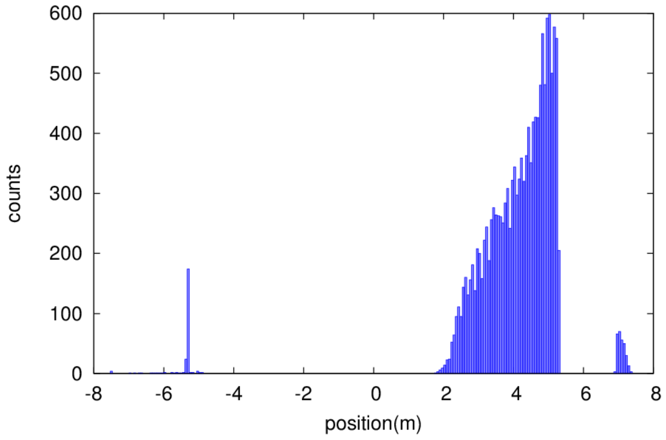


BG

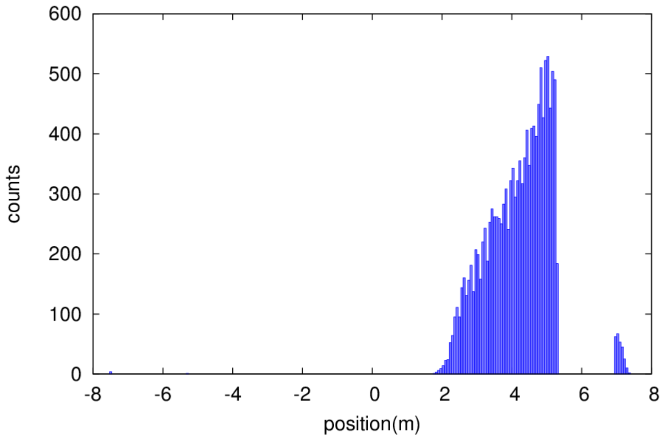
events



Without collimator



With collimator



BTH

Collimator design

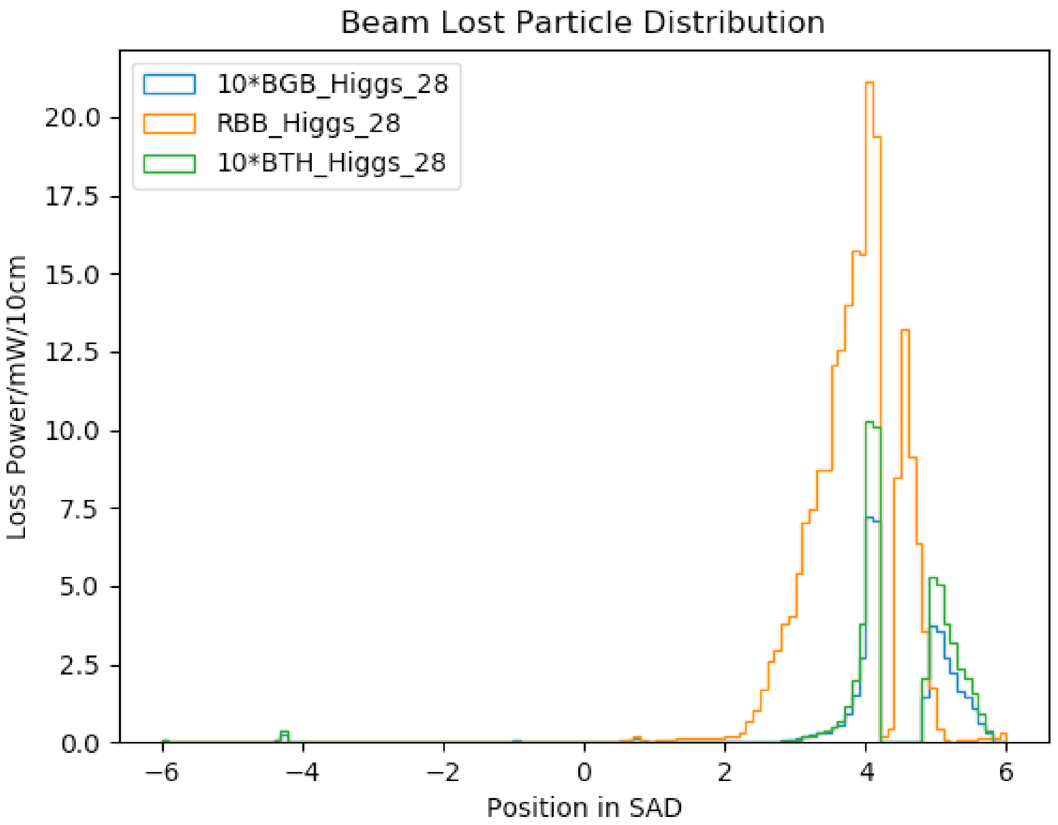
- Beam stay clear region: 18 σ_x+3mm, 22 σ_y+3mm
- Impedance requirement: slope angle of collimator < 0.1
- To shield big energy spread particles, phase between pair collimators: $\pi/2+n*\pi$
- Collimator design in large dispersion region: $\sigma=\sqrt{\varepsilon\beta + (D_x\sigma_e)^2}$

name	Position	Distance to IP/m	Beta function/m	Horizontal Dispersion/m	Phase	BSC/2/m	Range of half width allowed/mm
APTX1	D1I.785	2388.31	100.99	0.2	384.11	0.00181	1.81~8.42
APTX2	D1I.787	2325.75	100.99	0.2	384.36	0.00181	1.81~8.42
APTY1	D1I.791	2075.48	19.52	0.1995	387.46	0.003348	0.079~3.3
APTY2	D1I.793	2012.92	19.52	0.1995	387.71	0.003348	0.079~3.3
APTX3	D1O.5	1856.35	101.95	0.20	6.877	0.00182	1.82~8.45
APTX4	D1O.7	1918.92	101.95	0.20	7.127	0.00182	1.82~8.45
APTY3	D1O.10	2075.33	101.95	0.1	7.75	0.00182	0.182~3.67
APTY4	D1O.16	2388.17	101.95	0.1	9.00	0.00182	0.182~3.67

- horizontal collimator half width 4mm(13σ_x), Vertical collimator half width 3mm (22σ_y)
- The collimators will not have effect on the beam quantum lifetime.

Radiation background

- Including Radiative Bhabha, Beam-Gas, Beam Thermal Photon. Almost No Beamstrahlung.
- Normalized to loss power in mW(one beam).
- Higgs mode in CDR.



- Higgs Backgrounds on 1st layer of Vertex.
- With a safety factor of 10.

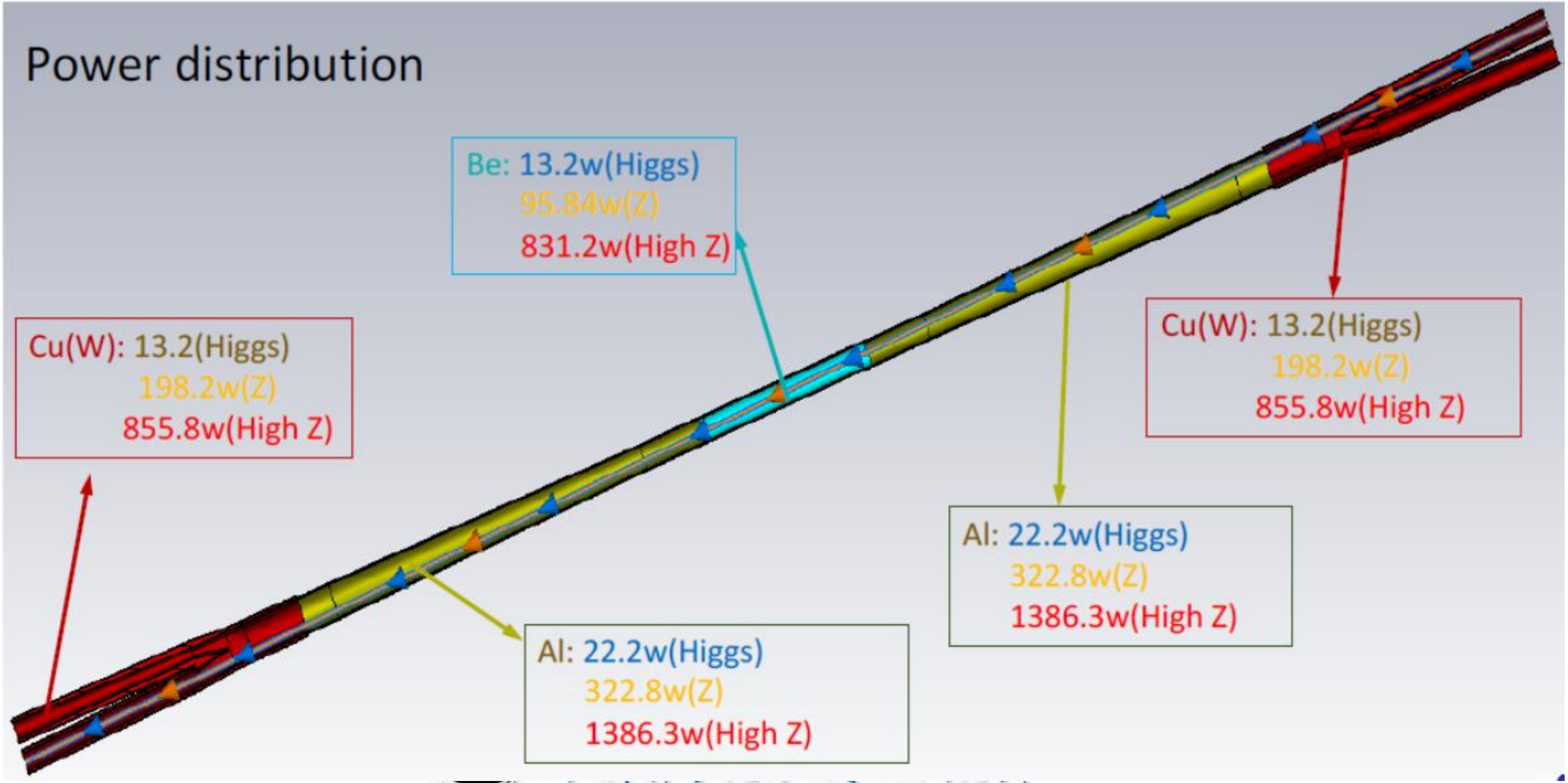
Background type	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)	1 MeV equivalent neutron fluence ($n_{eq} \cdot cm^{-2} \cdot yr^{-1}$)
Pair production	1.91	526.11	1.05×10^{12}
Synchrotron Radiation	0.026	15.65	
Radiative Bhabha	0.34	592.66	1.44×10^{12}
Beam Gas	0.9607	1235.9	3.37×10^{12}
Beam Thermal Photon	0.02	22.31	6.20×10^{10}
Total	3.2567	2392.63	5.922×10^{12}

Heat load in IR from beam loss

Region	SR heat load from RBB	SR heat load from BS	SR heat load from BG	SR heat load from 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

Heat load in IR from beam loss background is so small, compared to synchrotron radiation and HOM.

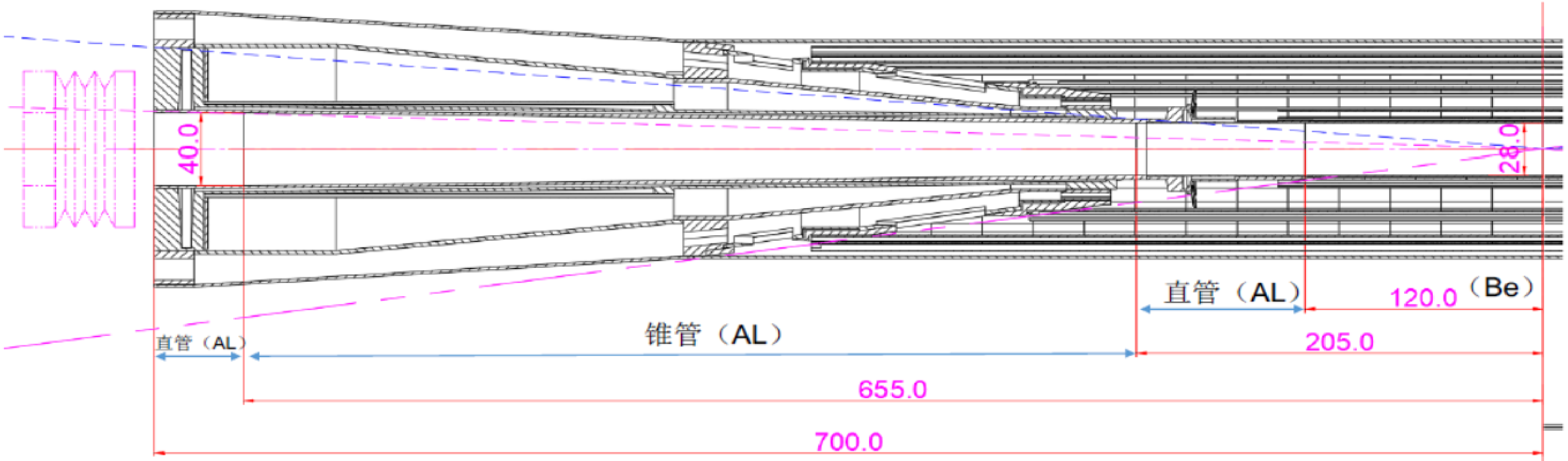
HOM power distribution



Beam pipe structure

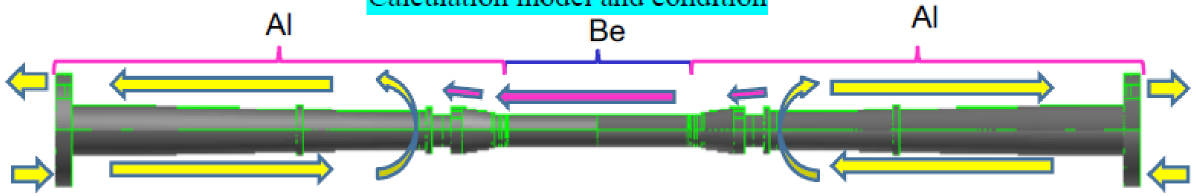
- Berryllium (central) and Aluminum(forward) beam pipes

From IP(mm)	Shape	Inner diameter(mm)	Material	Inner surface area(mm^2)	Marker
0-120	Circular	28	Be	10556	
120~205	Circular	28	Al	7477	
205~655	Cone	28~40	Al	48071	Taper: 1.75
655~700	Circular	40	Al	5655	



Beam pipe thermal analysis

Calculation model and condition



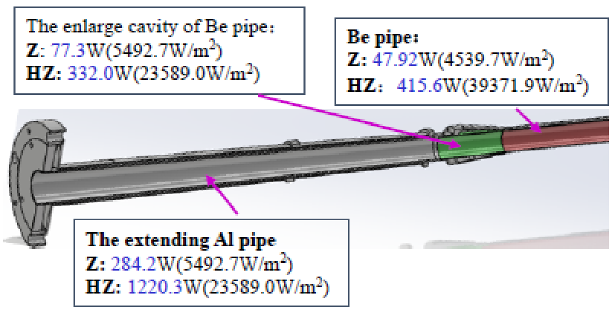
•Coolant: water
•Inlet temperature: 23°C
•Flow rate: 3.4L/min

•Coolant: paraffin
•Inlet temperature: 23°C
•Flow rate: 2.2L/min

•Coolant: water
•Inlet temperature: 23°C
•Flow rate: 3.4L/min

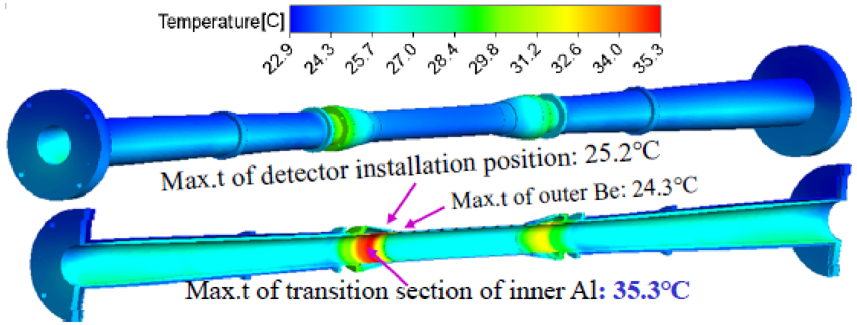
Viscous model: Laminar

Heat in each part of calculation model



CDR Z parameters

Temperature distribution in Z model



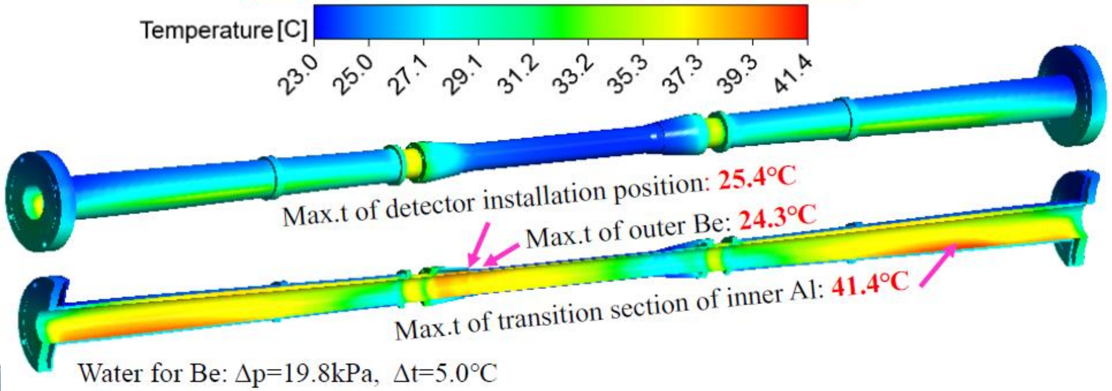
paraffin: Δp=19.8kPa, Δt=3.1°C
water: Δp=14.8kPa, Δt= 1.2°C

High Lumi Z parameters

With the heat deposition in High Luminosity Z mode, it becomes impossible to cool the Be beam pipe with oil. Water is chosen as the coolant for the demonstration purpose.

- Water flow rate for Be: 3.4L/min
- Water inlet temperature: 23^0C
- Other calculation condition is the same as before

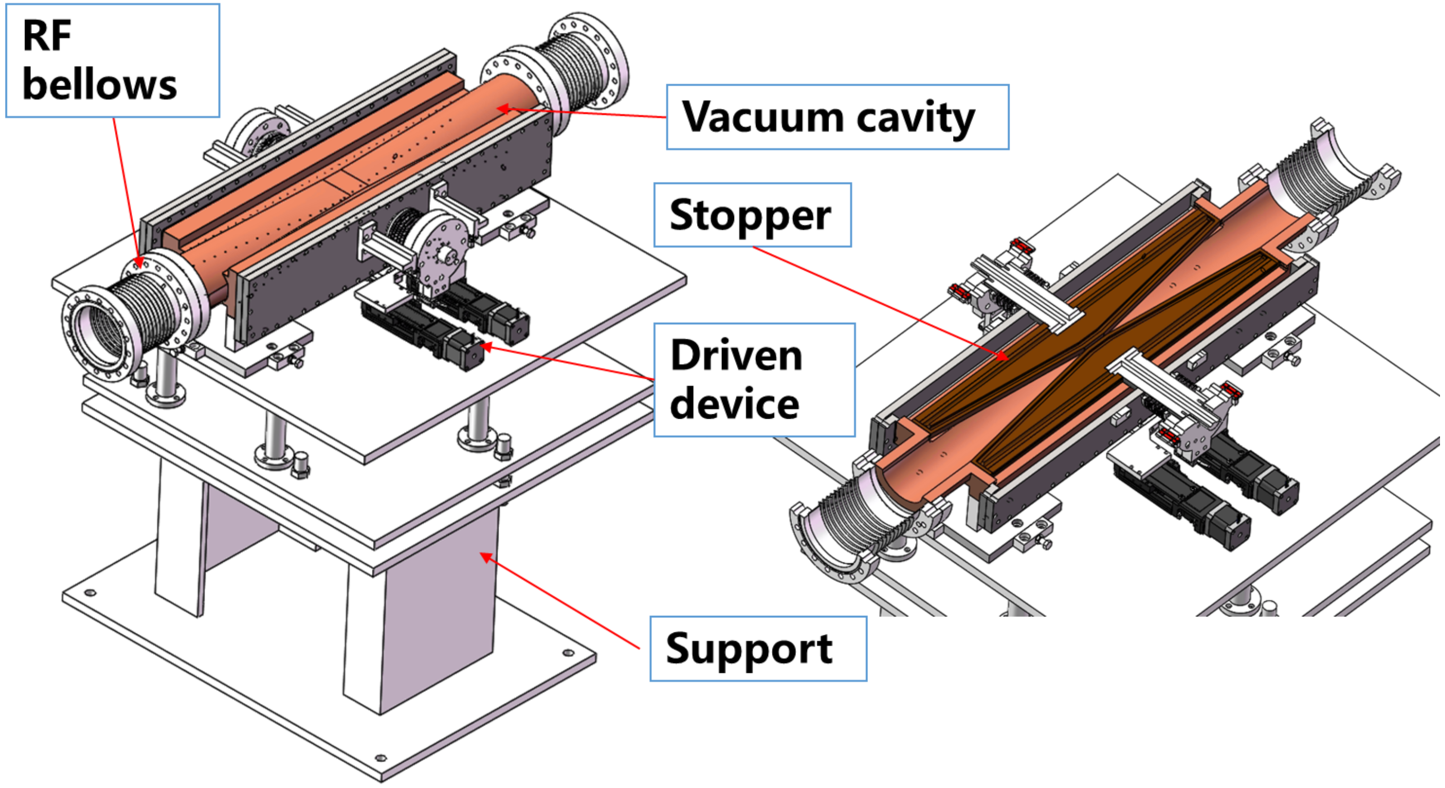
Temperature distribution in High Luminosity Z model



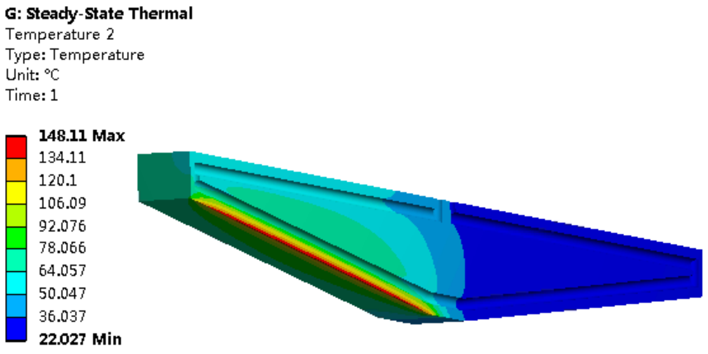
Water for Be: Δp=19.8kPa, Δt=5.0°C
Water for extending Al pipe: Δp=14.9kPa, Δt= 5.1°C

Movable collimators

- Located in straight section between two dipoles, the length is 800 mm.
- SR power: 7700W @120GeV, 30MW

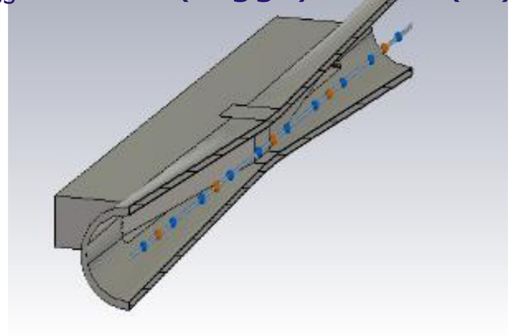


Highest temperature: 148 ℃

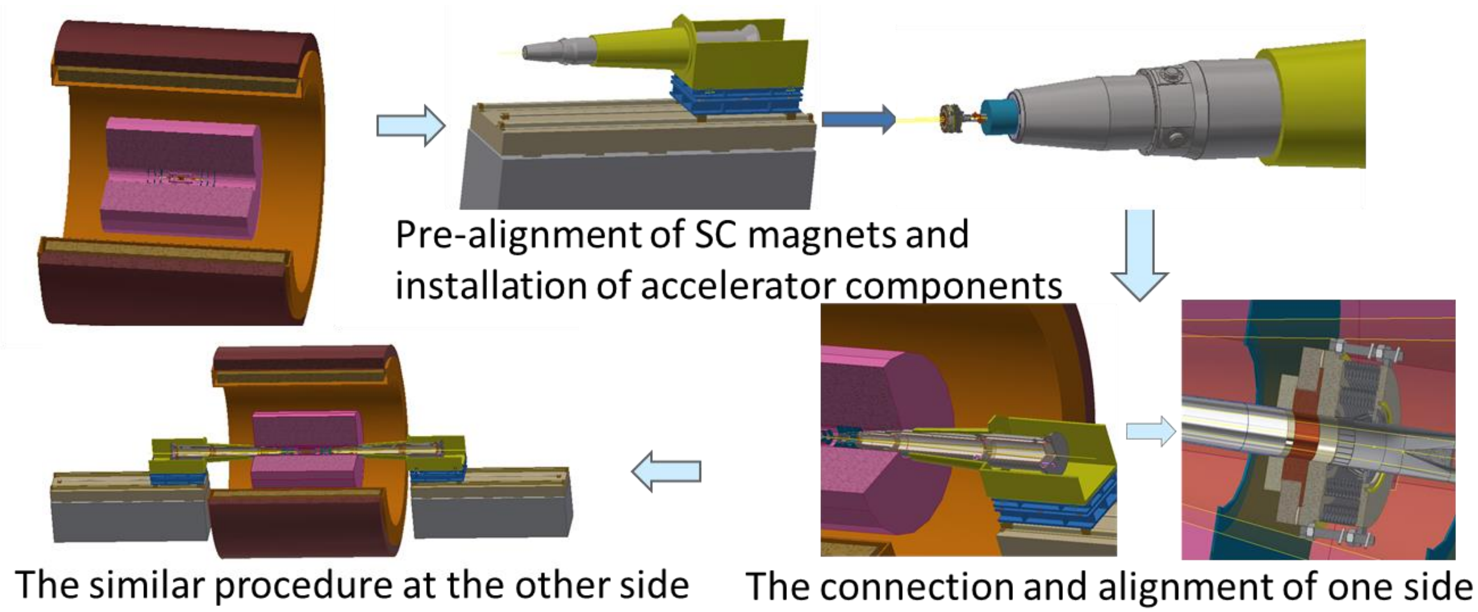


Loss-Factor: 0.045V/pC

P_{loss}: 18.8w(Higgs)/76.1w(W)/265.8w(Z)

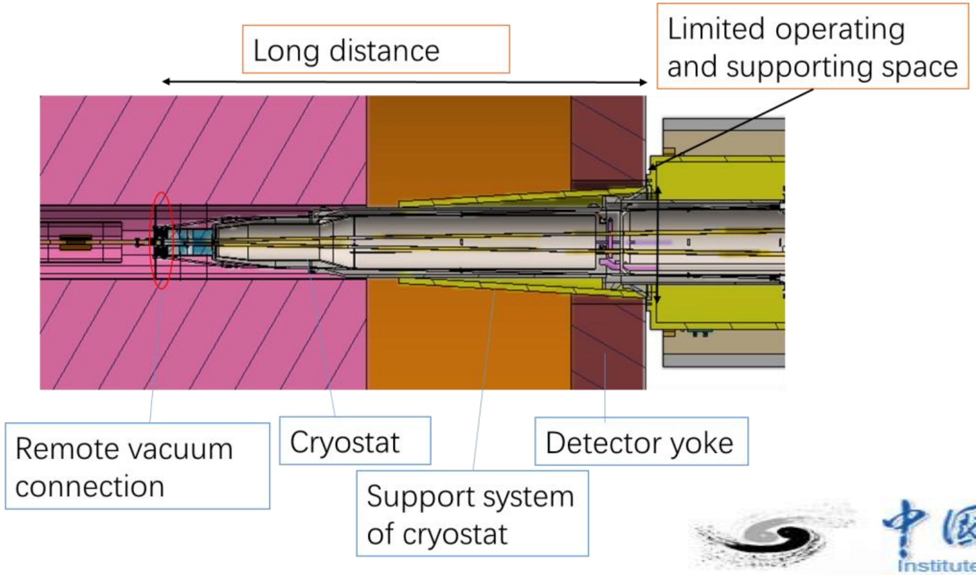


MDI integration and alignment

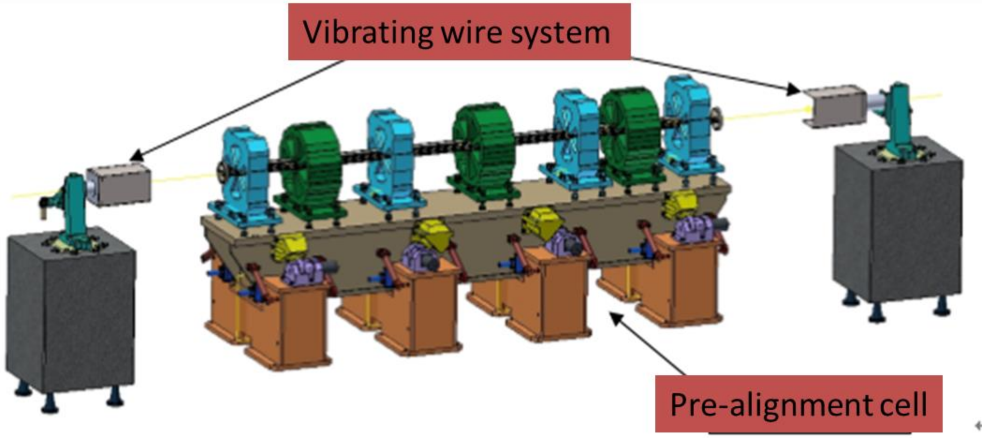


Alignment scenario:

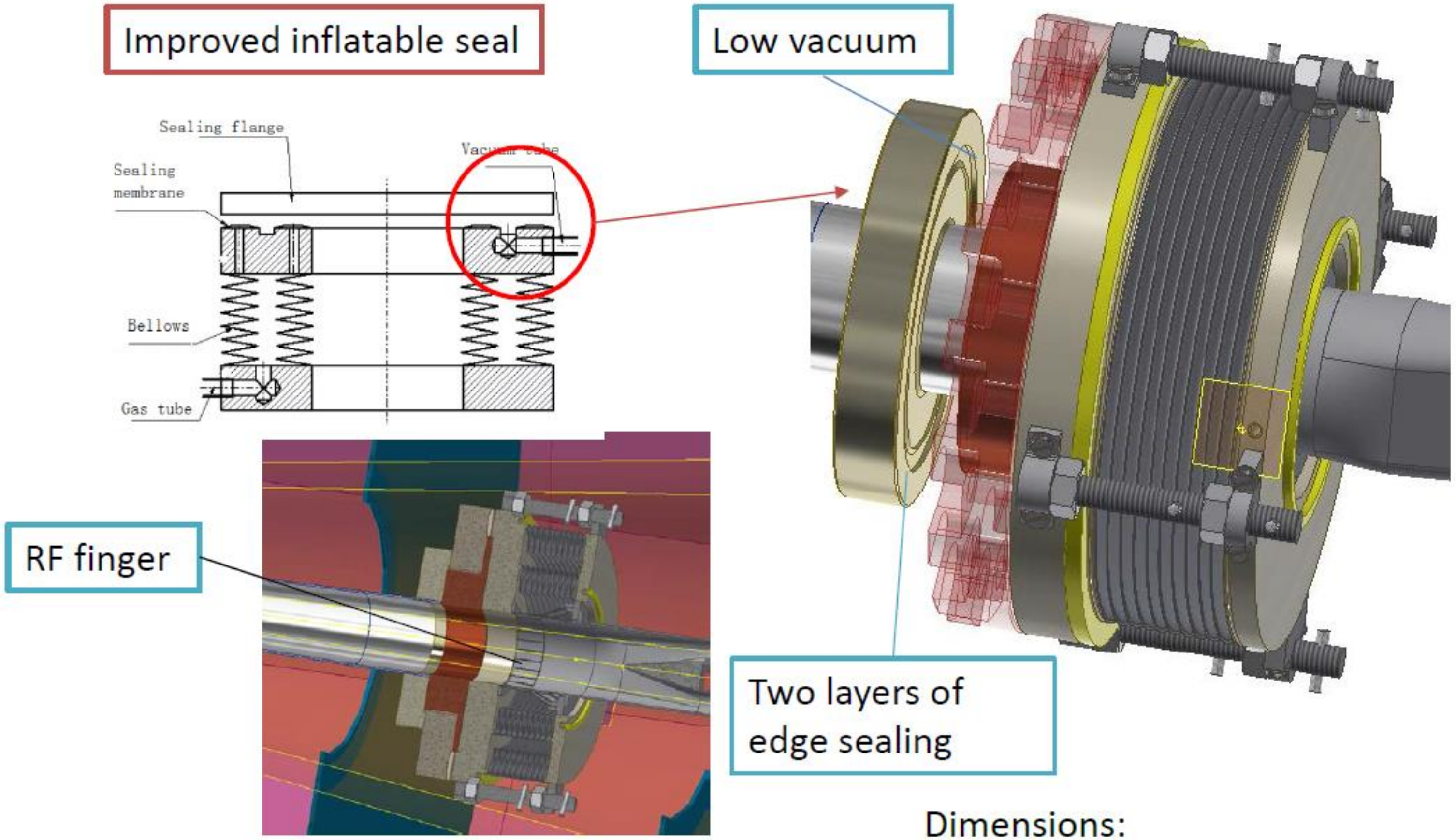
- Pre-align the SC magnets using vibrating wire system to "certain location" to compensate the effect of loads.
- Align the SC magnets in two cryostats using optical system.
- Measure misalignment using SSW and adjust by corrector magnets meet the alignment requirements.



VWS is a candidate pre-alignment method, accuracy of magnet centers: ≤10 μm



Remote vacuum connector



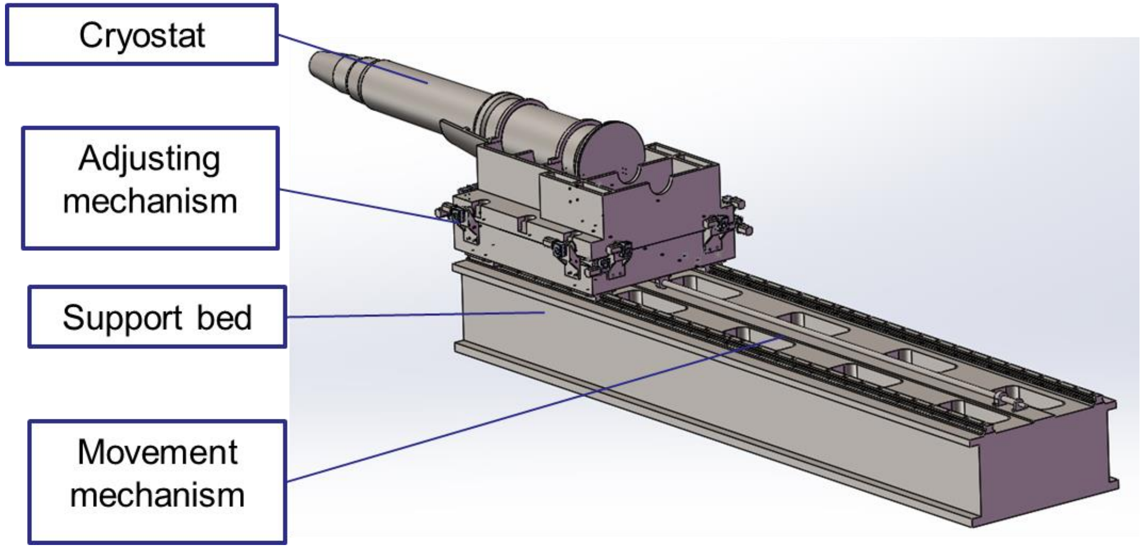
- Replace the sealing membranes by two layers of edge sealing.

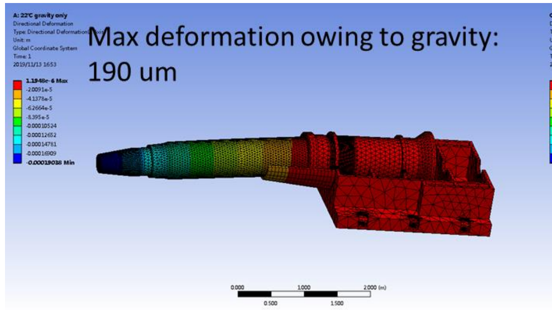
Dimensions:

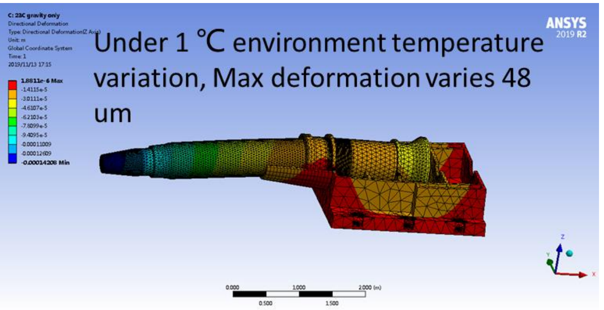
- Transversal: Max. φ174mm
- Longitudinal: ~83mm

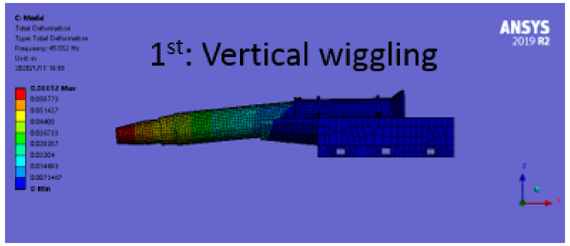
- **Difficulties:**
  - Transversal space: All the structure should be within detection angle.
  - Leak rate requirement: Ultra-high vacuum. Leak rate requirement: ≤2.7e-11Pa.m3/s
  - Longitudinal space: Bellows should absorb deformation when baking. →Add Z-direction support, length has been decreased to 83mm.
  - Minimize thermal loads: The thermal loads mainly includes SR power and HOM power.→ Avoid SR power by layout design, and decrease HOM power by RF finger.
  - Cooling: It is hard to dissipate the heat at RF finger which is thin, low thermal conductivity and far from the coolant.→ FEA

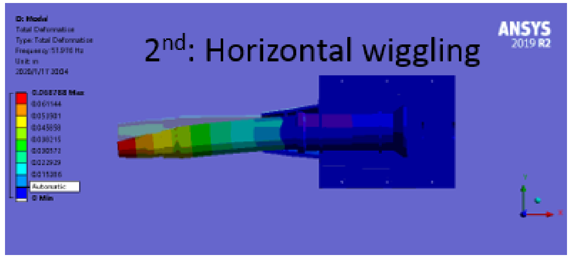
SC magnet supports











Key points

- ➢ Stability (static and modal)
- ➢ Accuracy
- ➢ Easy-operating
- ➢ Dimensions

Machine	Constraint	Requirements on ground motion (x/y)
Collider ring	luminosity reduction < 1%	< -/4nm
Booster ring	injection efficiency reduction < 1%	< 150/100nm
Injector linac	total emittance growth < 30%	< 200/250nm

- ➢ High stiffness for stability ⟵ conflict ⟶ Flexibility for high accuracy.
- ➢ Studies on support stiffness is on-going.
- ➢ Motor driven wedges jacks for high stiffness and accuracy.
- ➢ Auxiliary support, high damping material/structure are also in consideration

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Physics, Chinese Academy of Sciences

Summary

- The final focusing length has changed from 2.2m to 1.9m in High Luminosity Higgs.
- There is no SR photons hitting the central beam pipe in normal conditions.
- Single layer beam pipe with water cooling, SR heat load is not a problem.
- SR photons hitting the bellows under the extreme beam conditions, temperature rise ~1^0C
- Beam loss background in High luminosity Higgs with collimators can be reduced to the same level in CDR.
- Hit density on first layer of vertex detector is low from radiation background.
- Heat load in IR is mainly from HOM, especially in High luminosity Z mode.
- With the heat deposition in High Luminosity Z mode, it becomes impossible to cool the Be beam pipe with oil. Water is chosen as the coolant for the demonstration purpose.
- Highest temperature on collimators from SR and HOM is 148 ℃
- MDI alignment system is preliminary considered and designed.
- Replace the sealing membranes by two layers of edge sealing.

Thanks