CEPC MDI Study Status

Haoyu SHI

On behalf of the CEPC MDI Study Group

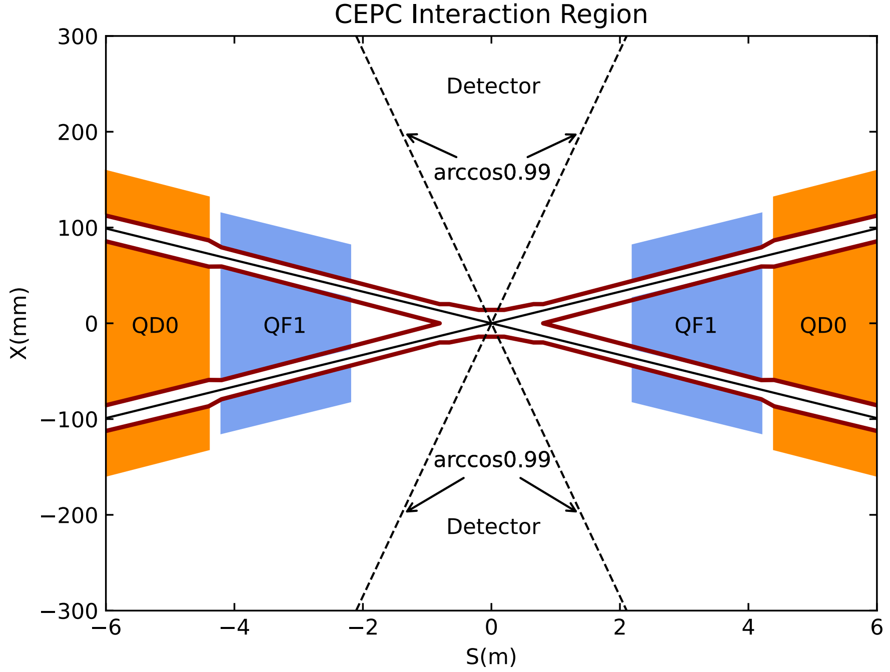
2021.10.22, Dongguan

Outline

- Introduction
  - What is MDI? Why MDI Study so important?
  - What are the inputs of current MDI Study?
- Map of MDI Study
  - What belongs to MDI?
- Current Study Status
  - Summary of baseline design
  - Novel design proposal
- Summary & Outlook

Introduction

- MDI stands for ”Machine Detector Interface”
  - Interaction Region and beyond
- The design of IR is challenging
  - The design of the components is challenging
    - Superconducting Magnets
    - Cryostat
    - Etc.
  - The overall design is complex
    - Lots of components in limited space
    - Make them all work, take interactions into account



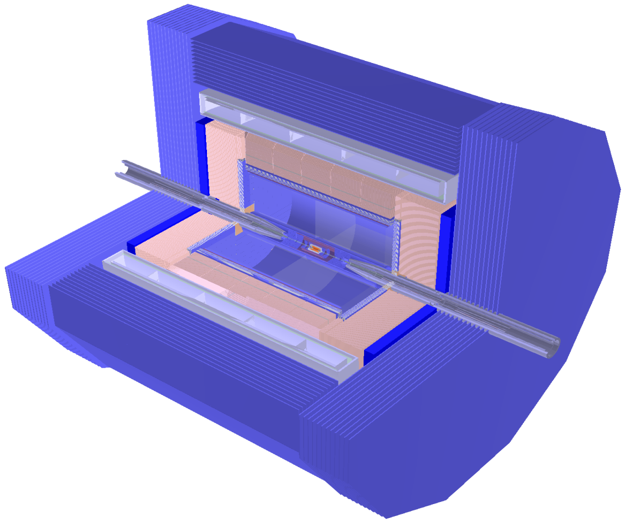
- For CEPC CDR, the interaction region is ± 6 m from the IP
- High Luminosity, low background and error

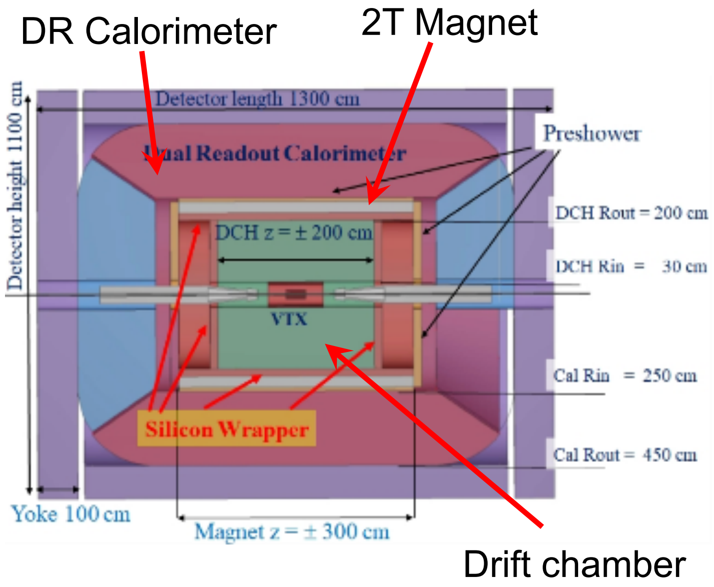
Introduction – Accelerator Parameters

	CDR Parameters				High Luminosity Parameters			
	Higgs	**W**	**Z（3T）**	**Z（2T）**	**tt**	**Higgs**	**W**	**Z**
Number of IPs	2				2			
Beam energy (GeV)	120	80	45.5		180	120	80	45.5
Circumference (km)	100				100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036		8.53	1.73	0.34	0.036
Half Crossing angle at IP (mrad)	16.5				16.5			
Piwinski angle	2.58	7.0	23.8		1.16	4.87	7.25	24.9
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0		20.1	16.3	15.0	15.2
Bunch number (bunch spacing)	242 (0.68μs)	1524 (0.21μs)	12000 (25ns+10%gap)		37 (4.45μs)	214 (0.7us)	1230 (0.27μs)	3816 (86ns)
Beam current (mA)	17.4	87.9	461.0		3.5	16.8	88.6	278.8
SR power /beam (MW)	30	30	16.5		30	30	30	**10**
Bending radius (km)	10.7				10.7			
Momentum compact (10^{-5})	1.11				0.71	0.71	1.43	1.43
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	1.04/2.7	0.33/1	0.21/1	0.13/0.9
Emittance e_x/e_y (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016	1.4/0.0047	0.64/0.0013	0.87/0.0017	0.27/0.0014
Beam size at IP s_x/s_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04	39/0.113	15.0/0.036	13/0.042	6.0/0.035
Beam-beam parameters ξ_x/ξ_y	0.031/0.109	0.013/0.106	0.0041/0.056	0.0041/0.072	0.071/0.1	0.015/0.11	0.012/0.113	0.004/0.127
RF voltage V_{RF} (GV)	2.17	0.47	0.10		10	2.2	0.7	0.12
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)				650 (216816)			
Natural bunch length σ_z (mm)	2.72	2.98	2.42		2.23	2.25	2.7	2.75
Bunch length σ_z (mm)	3.26	5.9	8.5		2.66	4.42	5.4	9.6
Natural energy spread (%)	0.1	0.066	0.038		0.17	0.19	0.12	0.12
Energy acceptance requirement (%)	1.35	0.4	0.23		2.3	1.6	1.2	1.3
Energy acceptance by RF (%)	2.06	1.47	1.7		2.6	2.2	2.5	1.7
Lifetime (hour)	0.67	1.4	4.0	2.1	0.3	0.205	0.917	1.34
Luminosity/IP L ($10^{34}cm^{-2}s^{-1}$)	2.93	10.1	16.6	32.1	**0.5**	**5.0**	**16.0**	**115.0**

Introduction – Detector Designs

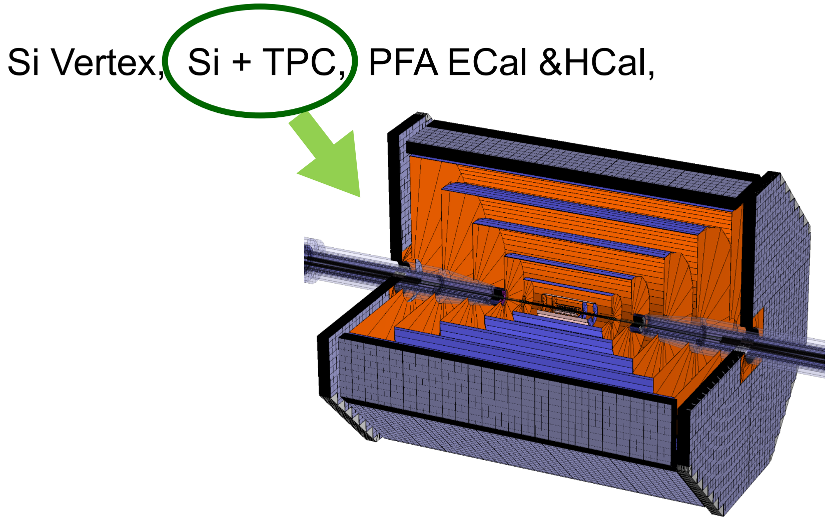
Particle Flow Approach
(ILD-like)

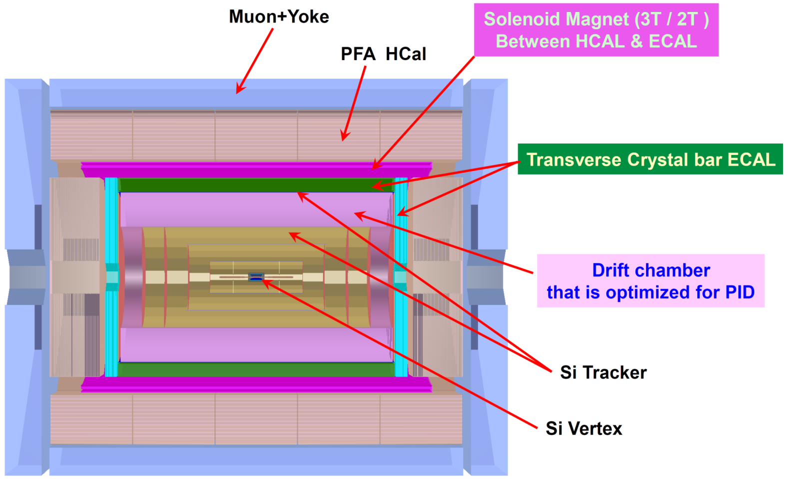




IDEA concept
(also proposed for FCC-ee)

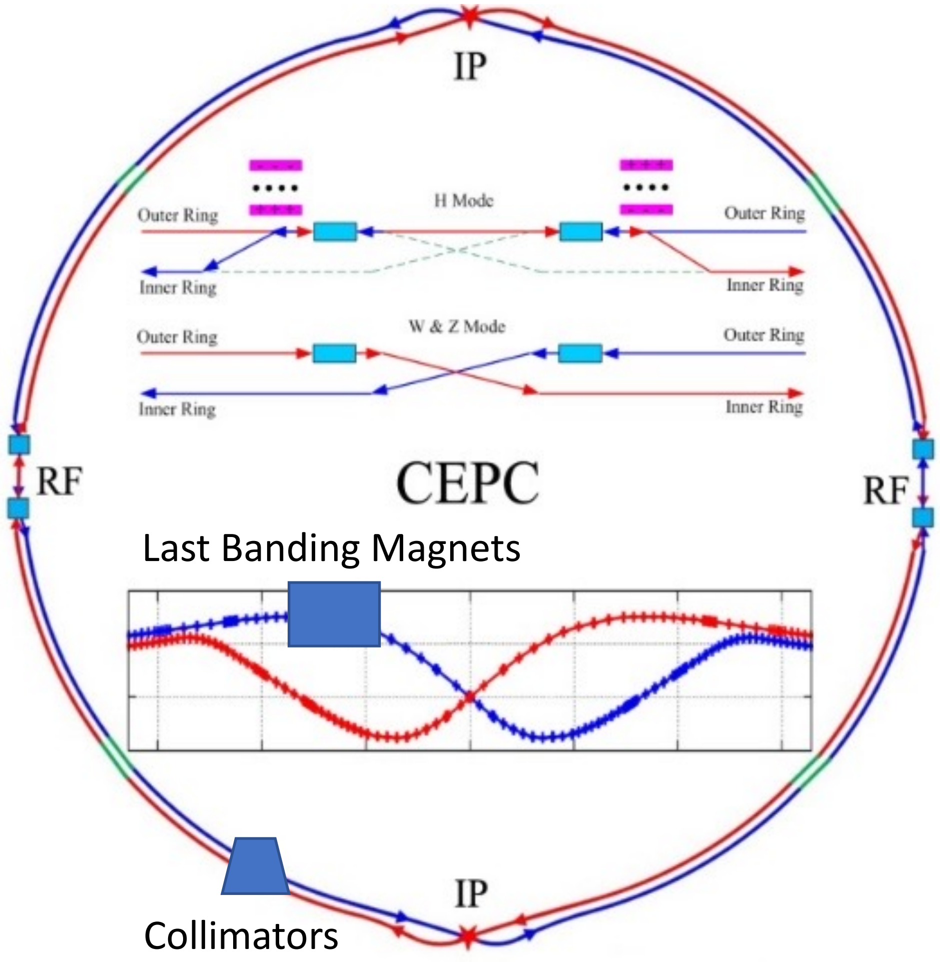
Full Silicon Tracker (FST) concept





4^{th} Detector concept

Map of the MDI Study



Accelerator

- IP Feedback
- BG Simulation
- LumiCal
- HOM absorber
- Vacuum Chamber
- SR Masks
- QD0/QF1
- Anti-Solenoid
- Cryostats
- BPMs
- Instability&Impendance
- Cooling
- Shielding
- Assembly&Supporting
- Alignment
- Connecting System
- Vacuum pumps
- Last Bending Magnet
- Collimators
- Control

Detector

- Central Beam Pipe
- Vertex Detector
- LumiCal
- Silicon Tracker
- TPC
- Hcal
- Ecal
- Solenoid
- Yoke
- Muon Detector
- Hall
- BG Simulation&Shielding
- Software Geometry
- Alignment&Assembly
- Electronics
- Cryogenic
- Radiation Protection
- Booster

The inputs of baseline design

- Dedicated to CDR parameters of the accelerator, and the baseline design of the detector.
  - 28mm Be beam pipe

CDR Parameters(2T for Z)

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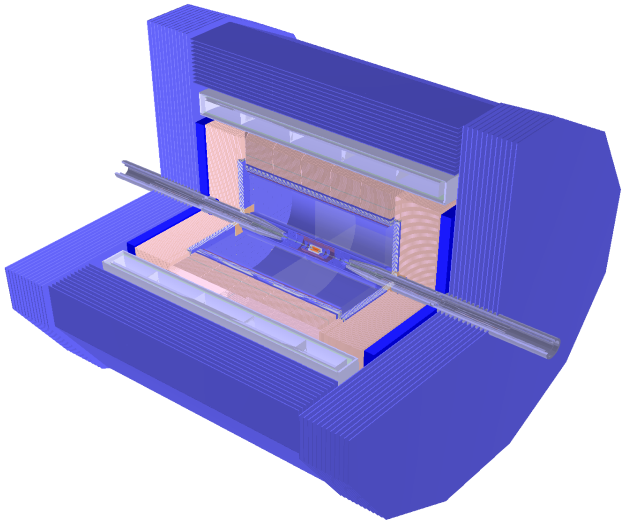
Baseline Detector



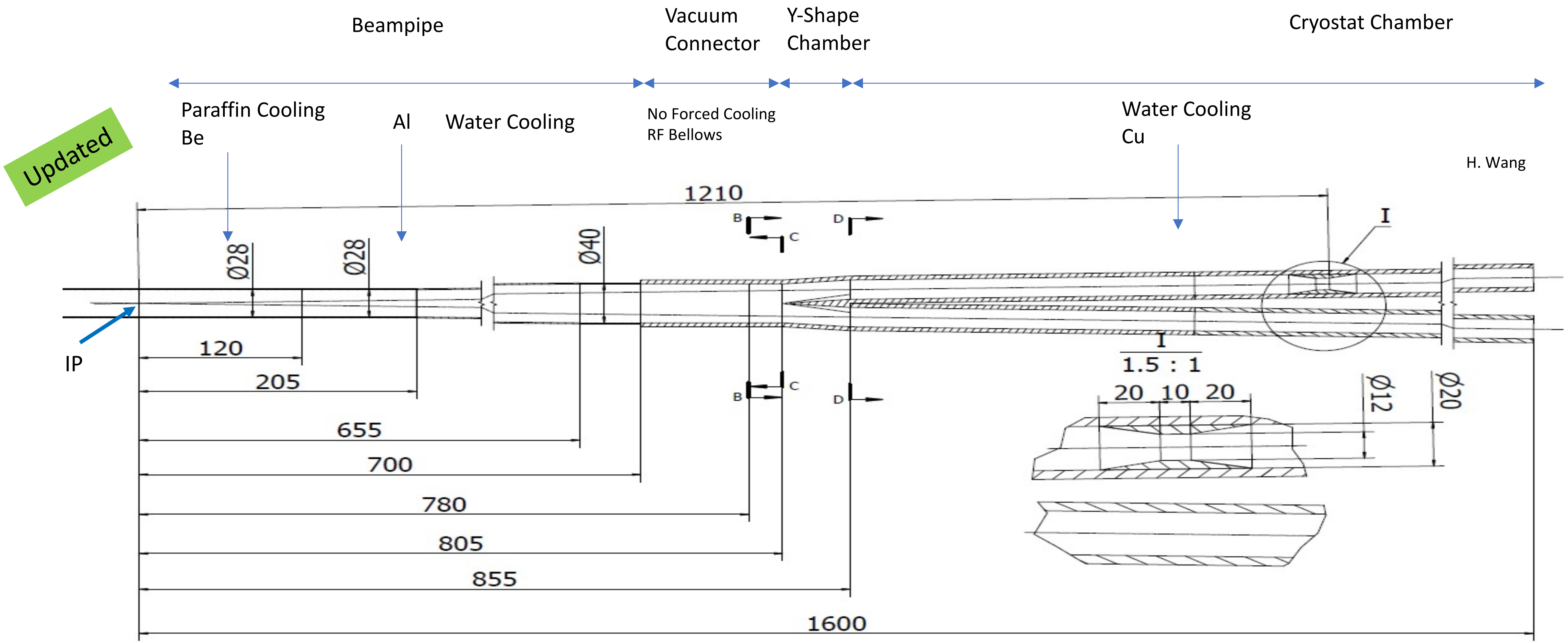
The MDI Table

Updated

	Range	Peak field in Coil	Central Field 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	33mard												
MDI Length	±6m												
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	68mm	1.6MeV	299keV	1568W	74W
Lumical	0.805 ~ 0.855m												
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					±12cm			28mm					
Last BM upstream	67.66~161.04m			1.1mrad	93.38m					45keV			
First BM downstream	46.06~107.04m			1.54mrad	60.98m					97keV			
Beampipe within QD0					2m			20mm					
Beampipe within QF1					1.48m								
Beampipe between QD0/QF1					0.23m								

The latest beampipe design

Nearly 20 versions tried in since last summer



The latest design

- Sensitive to beampipe design & Inputs
  - Collimators
  - Masks
  - LumiCal
- Not Sensitive to beampipe design
  - RVC
  - Magnets
  - Cryostat

The latest design

- Sensitive to beampipe design
  - Collimators
  - Masks
  - Lumical
- Not Sensitive to beampipe design
  - RVC
  - Magnets
  - Cryostat

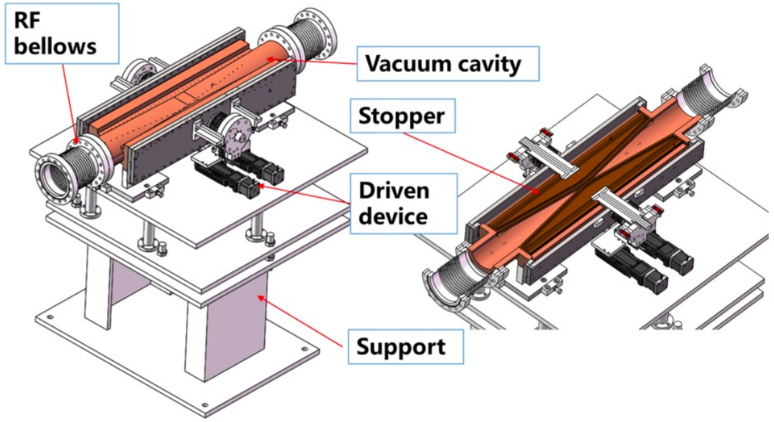
Physical Design
&
Mechanical Design

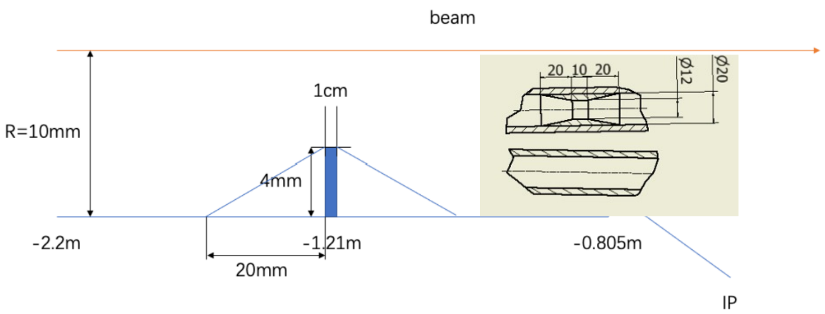
Collimators & Masks

- Collimators & Masks are indispensable for BG suppressing.
- 4 sets of horizontal collimators per ring till now.
  - Upstream beam loss have been reduced to low level.
  - We are sure to need more.
  - Preliminary design of the movable collimator has been done.
- 4 SR Masks per ring till now.
  - -4.2m/-1.21 per IP.

Refer to Haijing's Talk

H. Wang

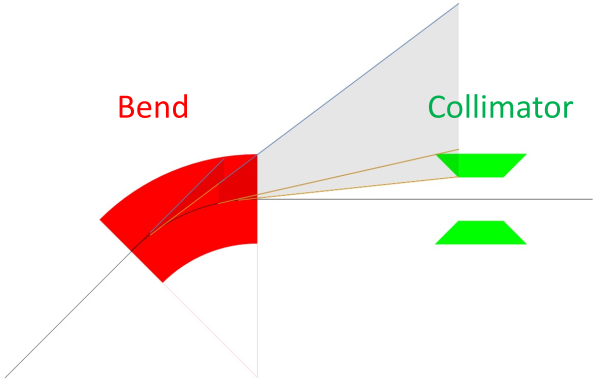


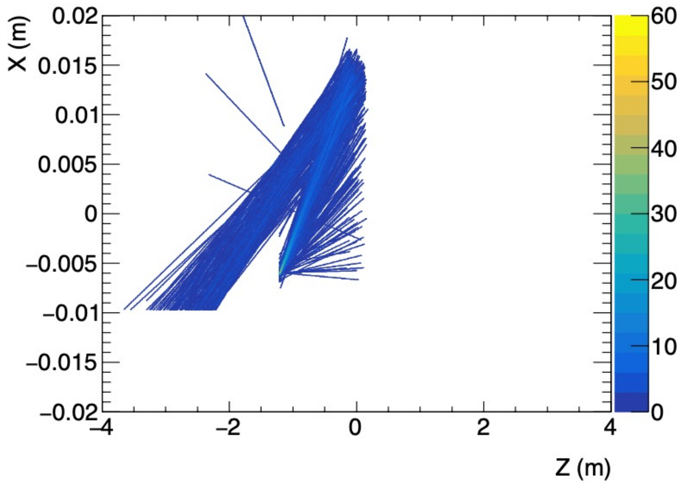


S. Bai

Name	Location	From IP
APTX1	D1I.1897	2139.06
APTX2	D1I.1894	2207.63
APTX3	D1O.10	1832.52
APTX4	D1O.14	1901.09

S. Bai

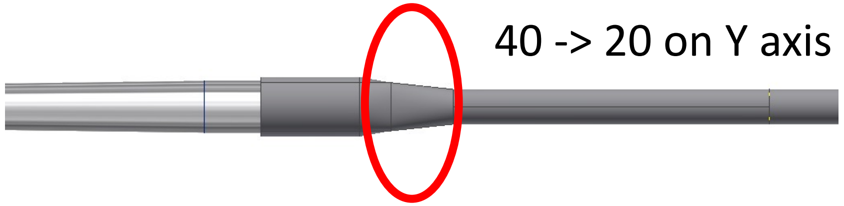


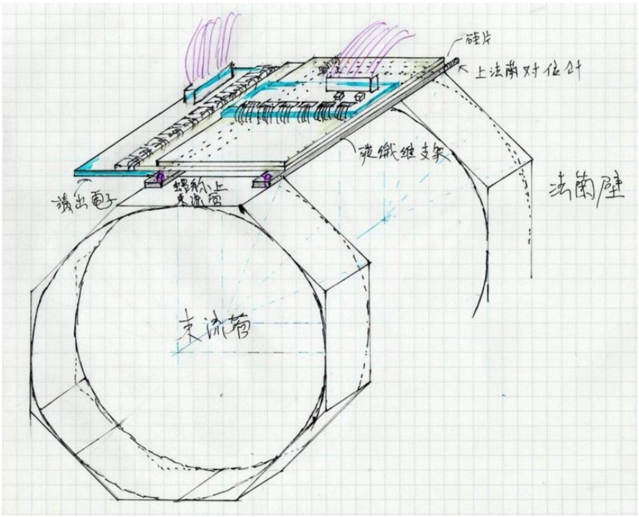


LumiCal

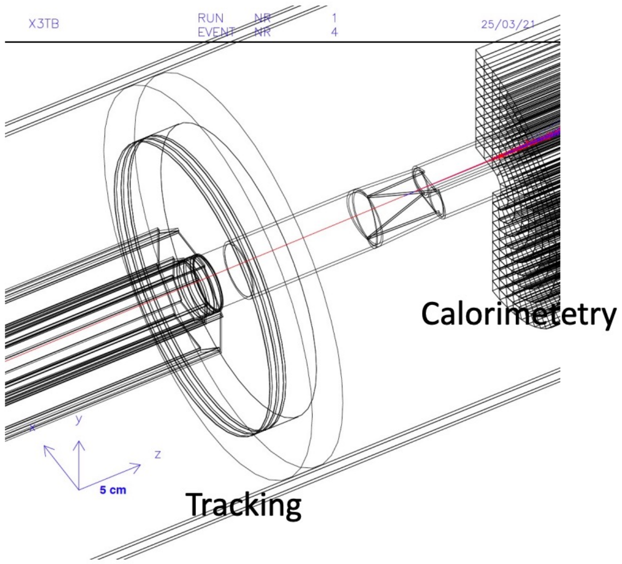
Refer to Suen's Talk

- LumiCal is necessary to achieve precision luminosity measurement as required for precision Higgs/EW measurement
- The new position of LumiCal has been chosen.
- Detector design and integration into IR





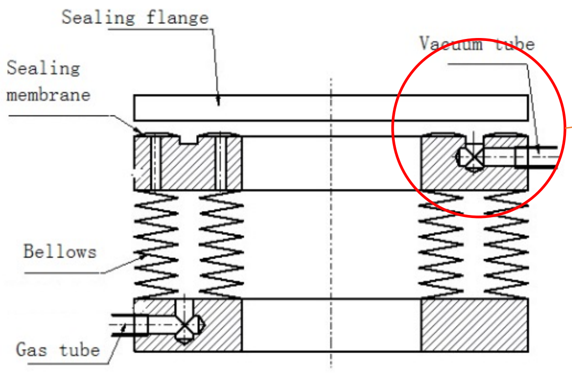
Tracking Devices



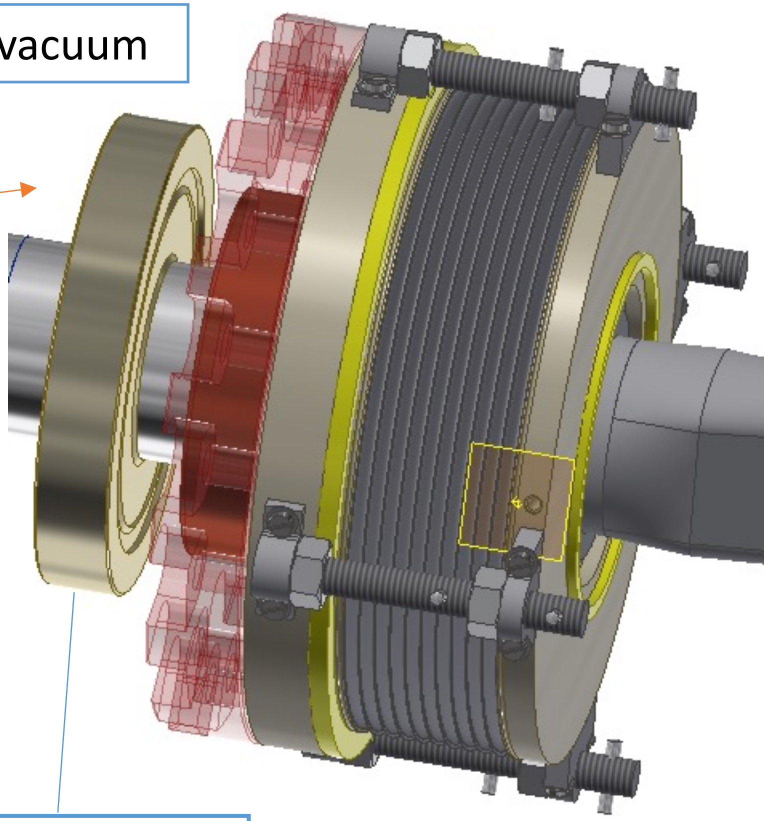
Remote Vacuum Connector(RVC)

Refer to Haijing's Talk

Improved inflatable seal

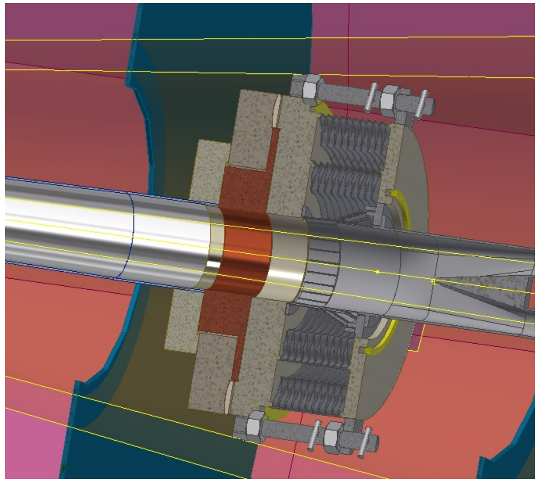


Low vacuum



Two layers of edge sealing

RF finger



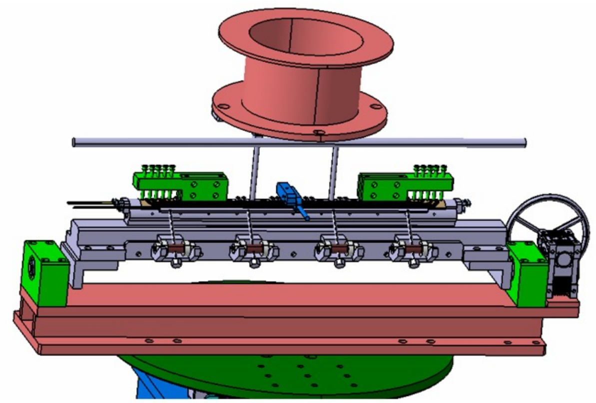
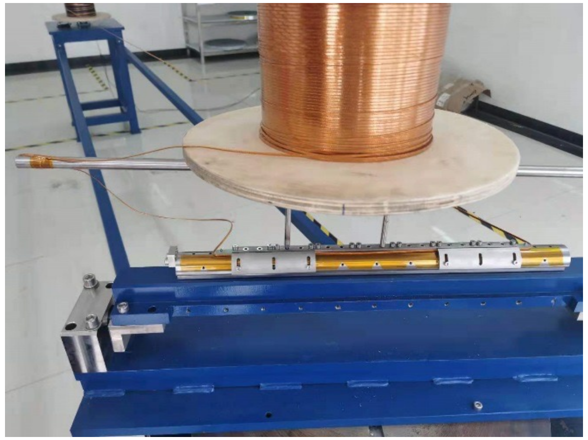
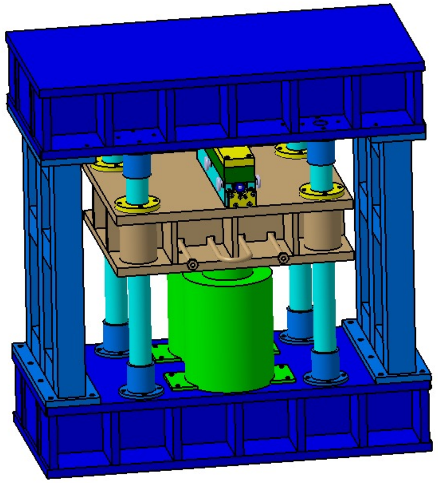
Location:
- 700~783mm away from IP

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

Magnets

Refer to Yingshun's Talk

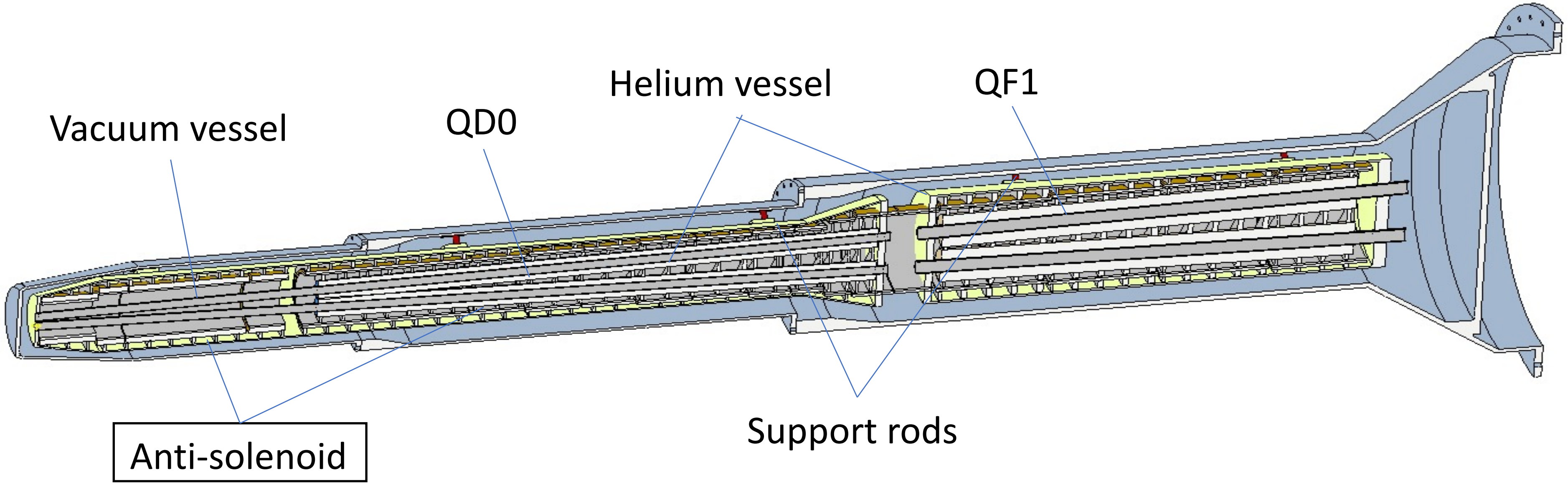
- QD0s locate at 2.2~4.2m from the IP, while QF1s locate at 4.35~6m from the IP.
- Study and research on key technologies of 0.5m single aperture QD0 short model (NbTi, 136T/m) is in collaboration with KEYE Company.
- Progress:
  - Fabrication of quadrupole coil winding machine, coil heating and curing system has been finished.
  - Fabrication of NbTi Rutherford cable is finished (12 strands).
  - Fabrication of QD0 short model magnet is in progress


Cryostat and Supporting

Refer to Miaofu & Haijing's Talk

- Cryostat Chambers locates at 1.2~6.0m from the IP. The length is ~4.8m.
- Nontrivial to install and support the magnets and its auxiliary components with sufficient accuracy and stability.



Safety Check?

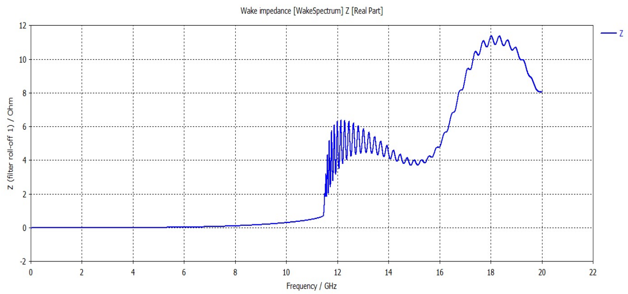
- Thermal Analysis(including impendence)
  - Source
    - HOM Heating
    - Synchrotron Radiation
    - Other Backgrounds(Negligible)
- Detailed Mechanical Design
- Backgrounds Estimation
  - Hotspot Shielding
  - Full Detector Simulation

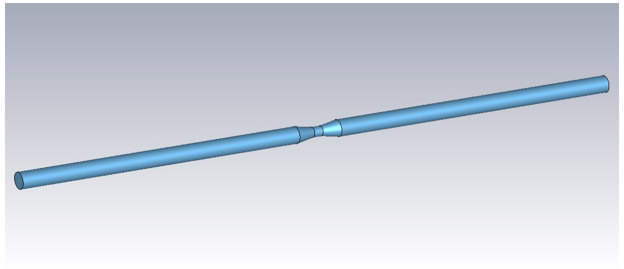
HOM & Impendence

Refer to Yudong's Talk

- The Power Distribution on Higgs & Z mode has been simulated.
  - The new SR masks has been considered.

距IP距离（mm）	形状	内径(mm)	材料	内表面积(mm²)	备注	总功率&Higgs (W)	功率密度&Higgs (W/cm²)	功率分布&Higgs (W)	总功率&Z (W)	功率密度&Z (W/cm²)	功率分布&Z (W)
0 – 120	圆直管	直径28	Be	10556		6.6	0.06	6.60	47.92	0.45	47.92
120-205	圆直管	直径28	Al	7477		22.2	0.04	2.71	322.8	0.53	39.44
205-655	圆锥管	直径28过渡到直径40	Al	48071	taper:1.75			17.44			253.54
655-700	圆直管	直径40	Al	5655				2.05			29.83
700-780	圆直管	直径40	Cu	10052	远程连接装置预留	13.2	0.03	2.60	198.2	0.39	39.05
780-805	圆面过渡到跑道型	水平方向直径40-40，垂直方向直径40-30.7	Cu	3124				0.81			12.14
805-855	跑道型过渡到两个圆面	上游直径12 下游直径20	Cu	6932				1.79			26.93
855-1110	上游圆锥管 下游圆直管	上游直径12过渡到20，下游直径20	Cu	30906				8.00			120.08





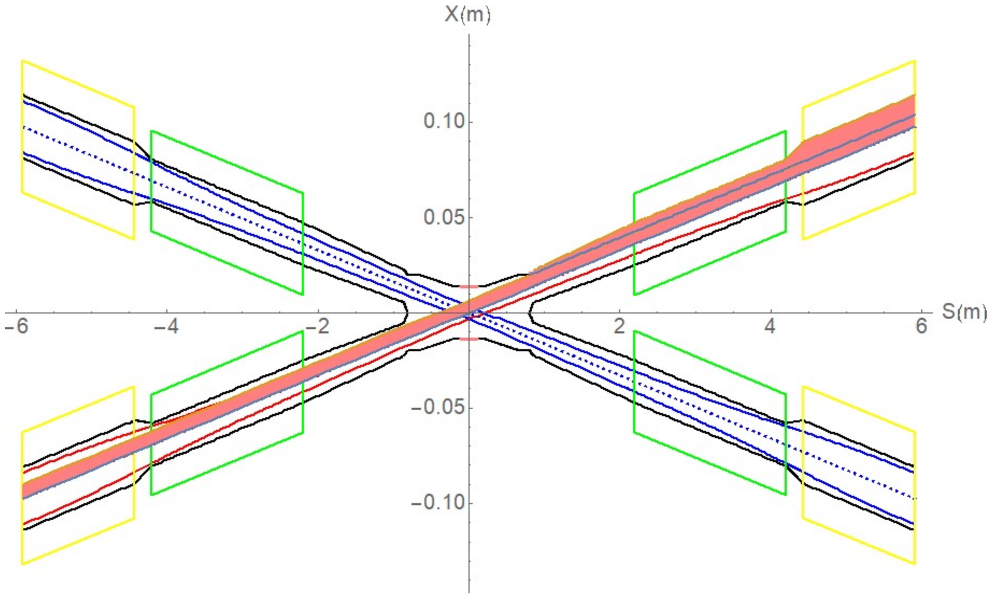
Loss factor(V/pc)	Power @Higgs	Power @W	Power @Z
$8.69*10^{-4}$	0.36 w	1.47 w	5.13w

Synchrotron Radiation

- Synchrotron radiation should be dealt with high priority at circular machines when designing the interaction region

Revised beam pipe design to achieve

No direct SR photons hitting the central beam pipe except the extreme beam conditions (e.g. beam off orbit due to magnet errors)



	Power Deposition	Average Power Density
0.805~0.855m	16W	88.9W/cm^2
0.855~2.2m	12.3W	2.54W/cm^2
QD0(2.2m~4.2m)	2.79W	0.39W/cm^2
QD0~QF1(4.2~4.43m)	36.1W	43.6W/cm^2
QF1(4.43m~5.91m)	3W	0.56W/cm^2

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Does this necessary?

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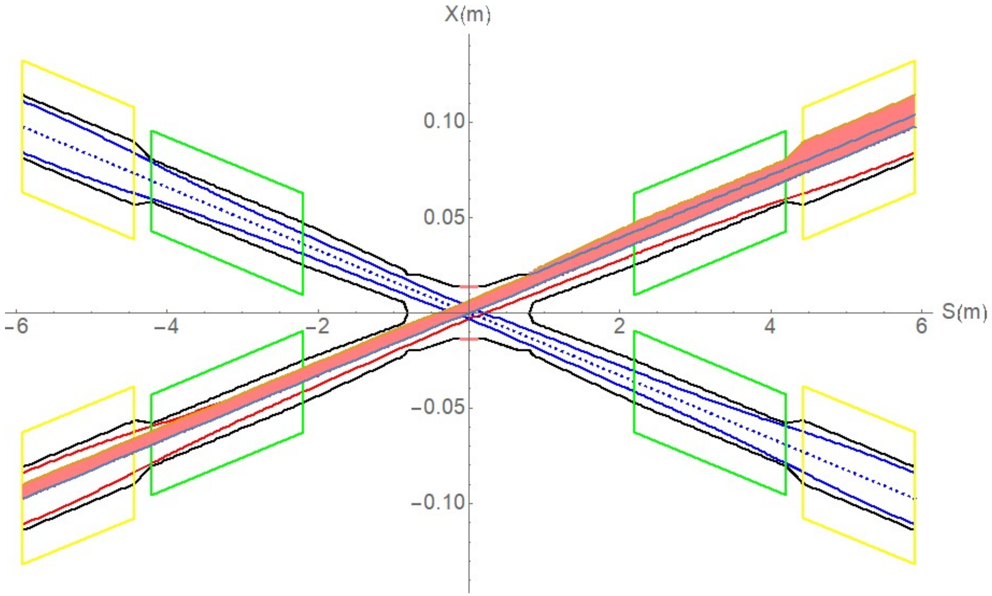

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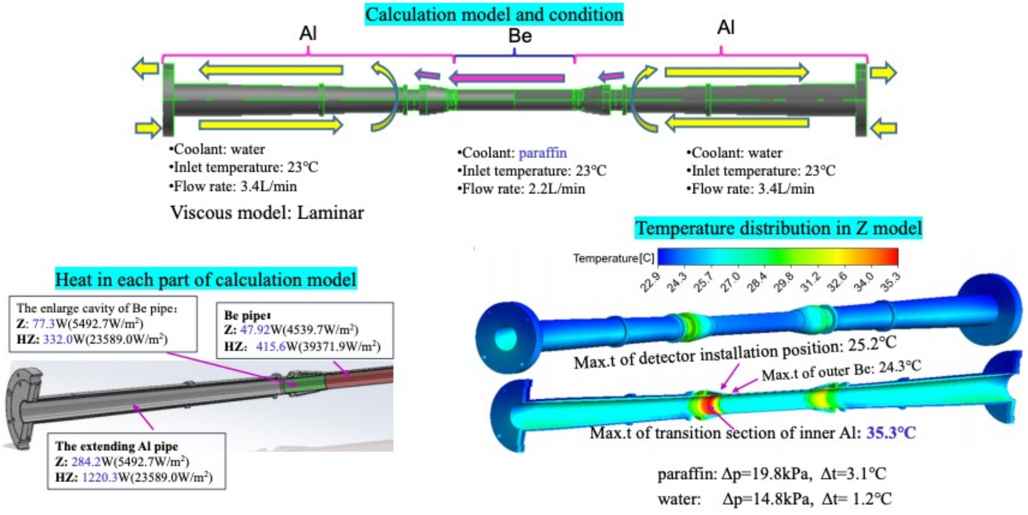
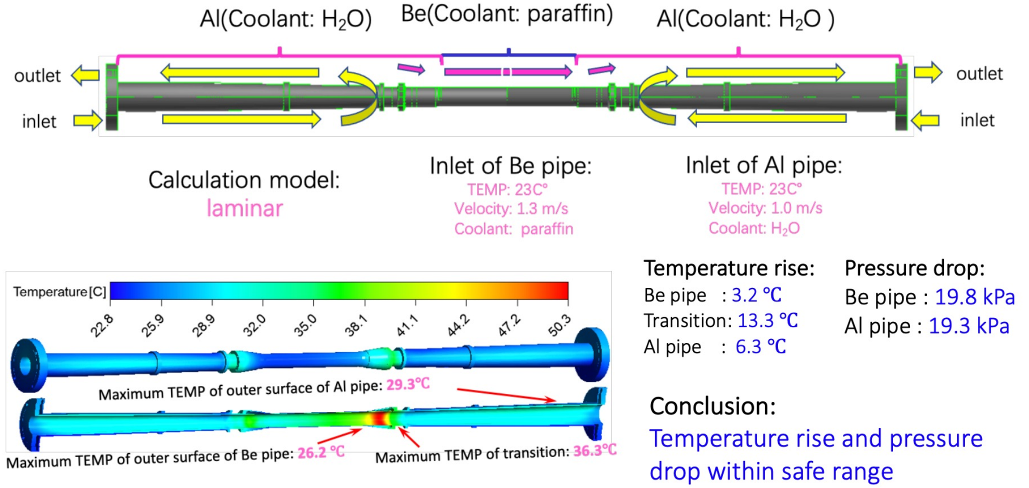
Thermal Analysis

Refer to several talks tomorrow



CDR Z parameters

- Pressure drop:
  - Be pipe : 19.8 kPa
  - Al pipe : 19.3 kPa
- TEMP rise:
  - Be pipe : 3.2 ℃ (between the inlet and the outlet)
  - Transition: 13.3 ℃
  - Al pipe : 6.3 ℃
- Temperature rise and pressure drop are in a safe range



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Pressure drop:
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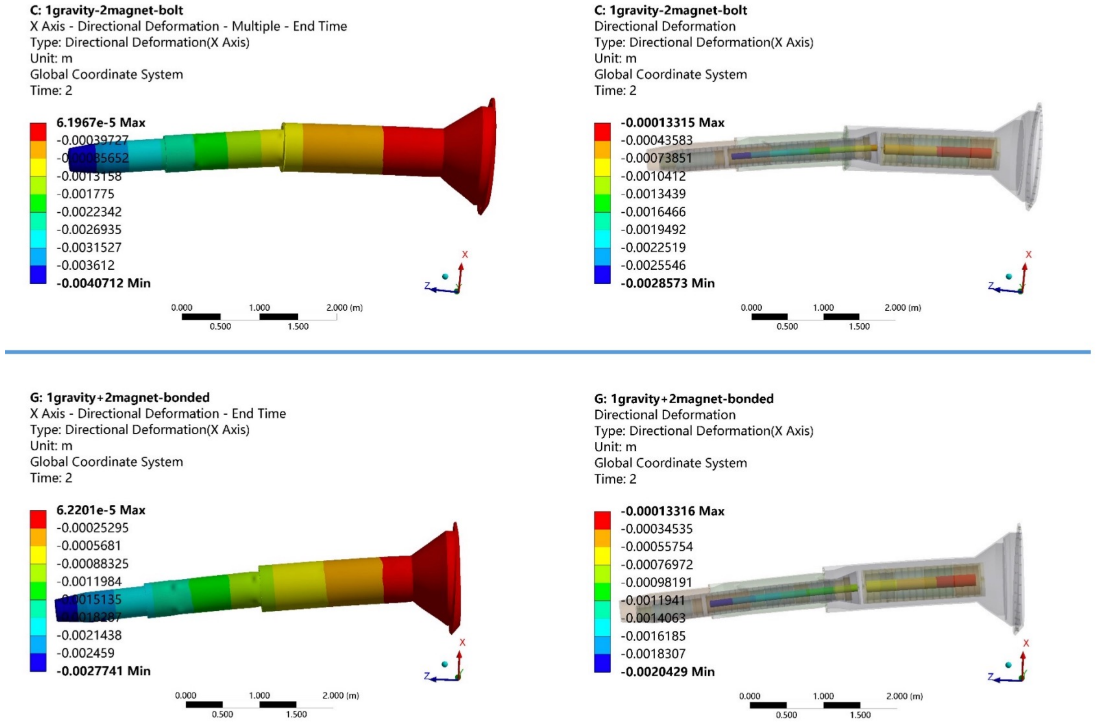
Conclusion:
Temperature rise and pressure drop within safe range

Mechanical Design

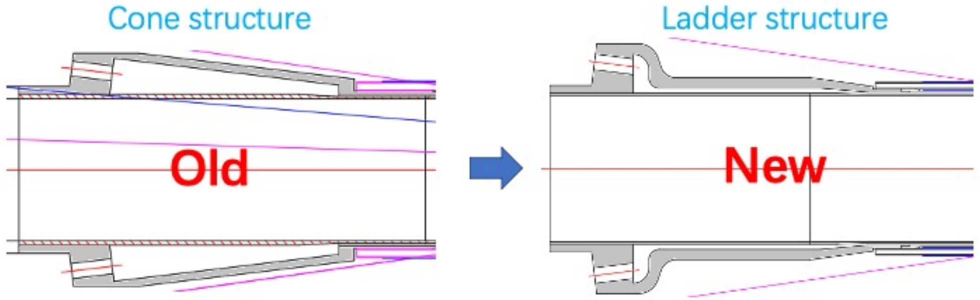
Refer to Haijing's talk

Refer to Songwen's talk

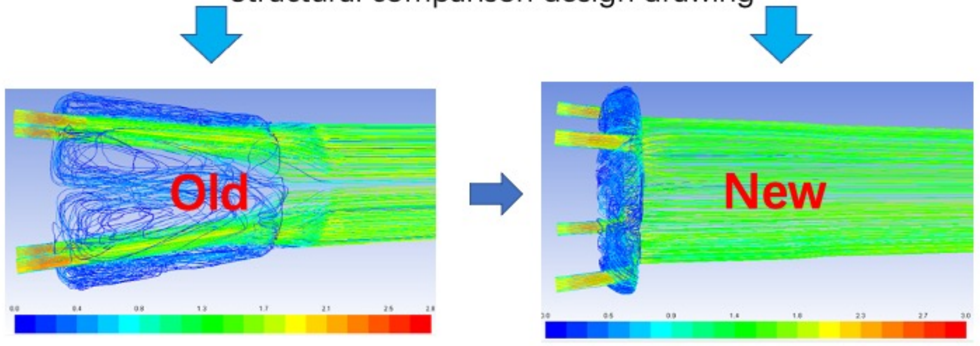
Deformation Calculation



Detailed Beampipe Design



Structural comparison design drawing

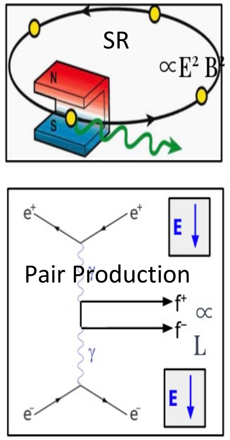


Streamline comparison chart

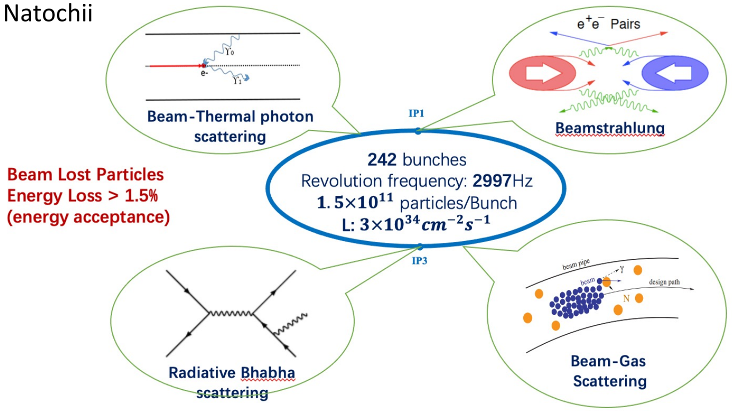
Background Estimation

- Whole-Ring generation for some BGs
- Multi-turn tracking
  - Using built-in LOSSMAP with one step ahead
  - SR emitting on
  - RF on
- Doing
  - 2 IR per ring
  - Magnet errors
    - No misalignment
    - High-order
  - Integrating to CEPCSW

A. Natochii

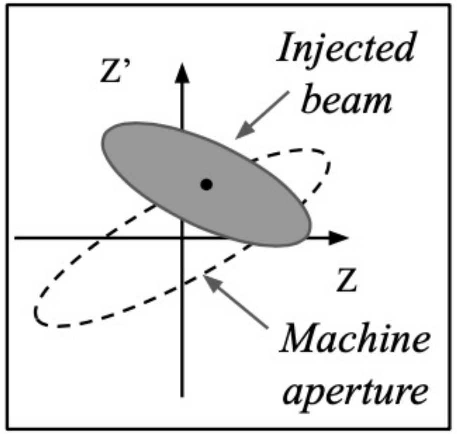


Photon BG



Beam Loss BG

A. Natochii



Injection BG

Updated

Background	Generation	Tracking	Detector Simu.
Synchrotron Radiation	BDSim	BDSim/Geant4	Mokka
Beamstrahlung/Pair Production	Guinea-Pig++	SAD	
Beam-Thermal Photon	PyBTH		
Beam-Gas Bremsstrahlung	PyBGB		
Beam-Gas Coulomb	BGC in SAD		
Radiative Bhabha	Bbbrem		

Detector Impact

- SR Hit Number on Be beam pipe per bunch crossing.

	Higgs	W	Z
Hit Number	~320	~28	<1

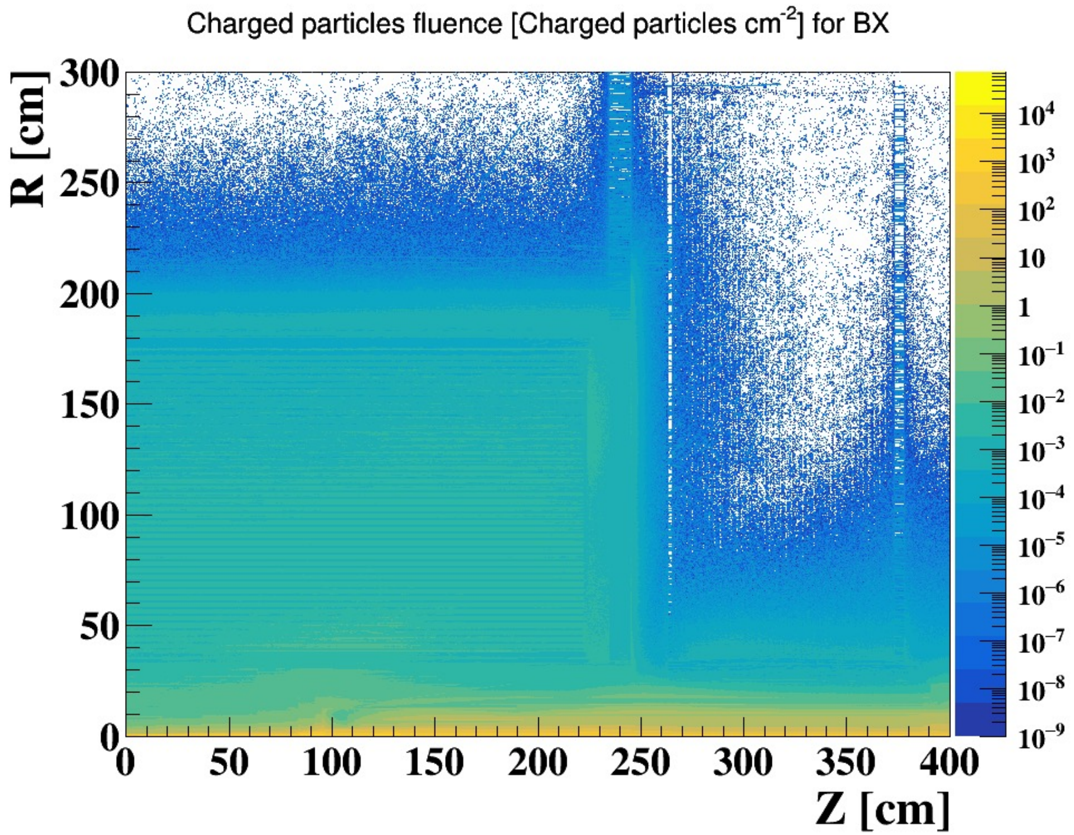
- Preliminary results on 1st layer of vertex. Safety factor of 10 applied.

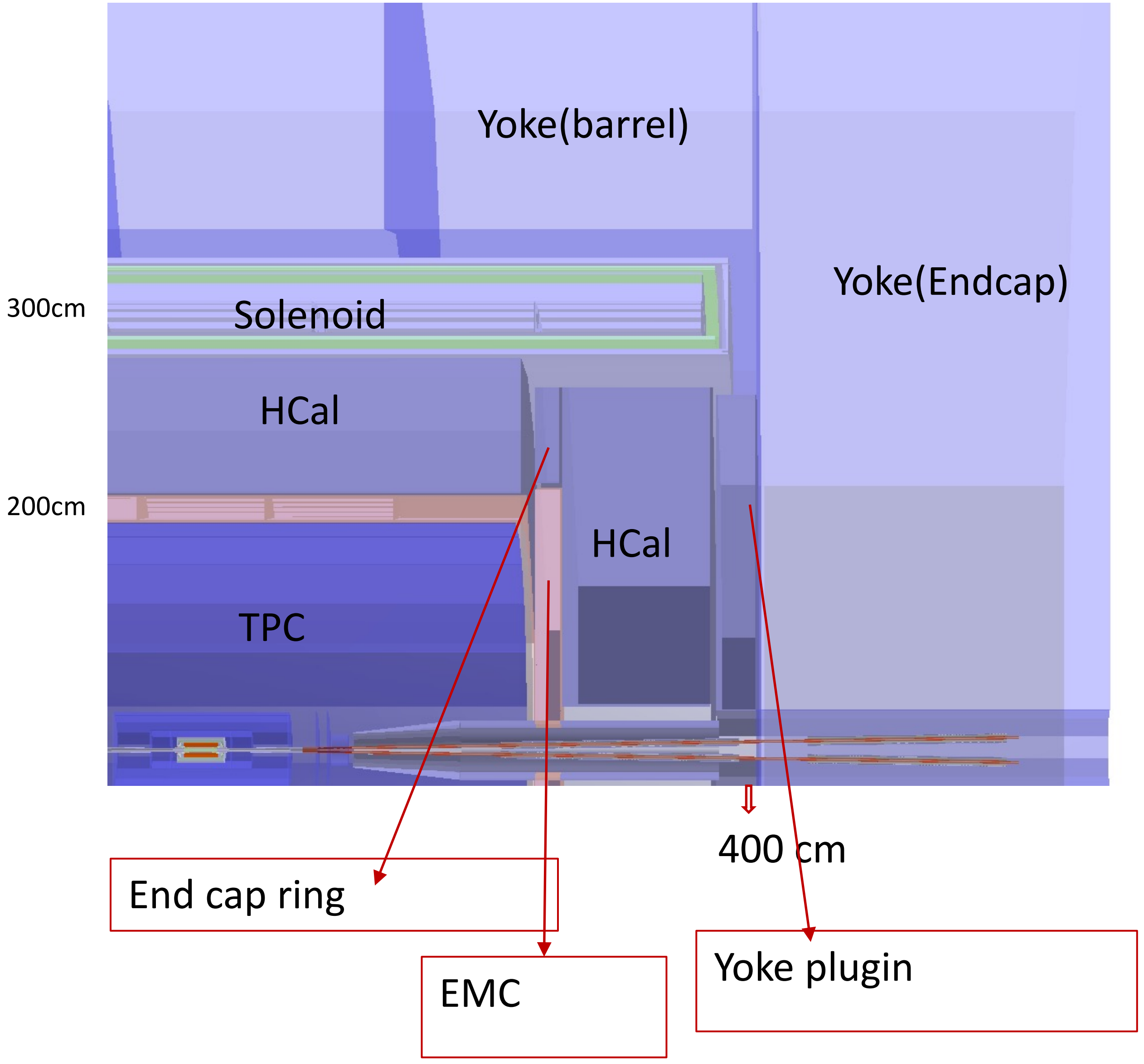
Background	Hit Density($cm^{-2} \cdot BX^{-1}$)			TID($Mrad \cdot yr^{-1}$)			1 MeV equivalent neutron fluence ($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)		
	Higgs	W	Z	Higgs	W	Z	Higgs	W	Z
Pair production	1.8	1.2	0.4	0.50	2.1	5.6	1.0	3.8	10.6
Beam Gas	0.4	0.4	0.2	0.36	1.3	4.1	1.0	3.6	11.1
Total	2.17	1.6	0.6	0.86	3.4	9.7	2.0	7.4	21.7
Total_oCDR	2.4	2.3	0.25	0.93	2.9	3.4	2.1	5.5	6.2

- Take Mask into Account(Higgs):

Background	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($Mrad \cdot yr^{-1}$)	1 MeV equivalent neutron fluence ($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)
Beam Gas	0.4	0.39	1.0

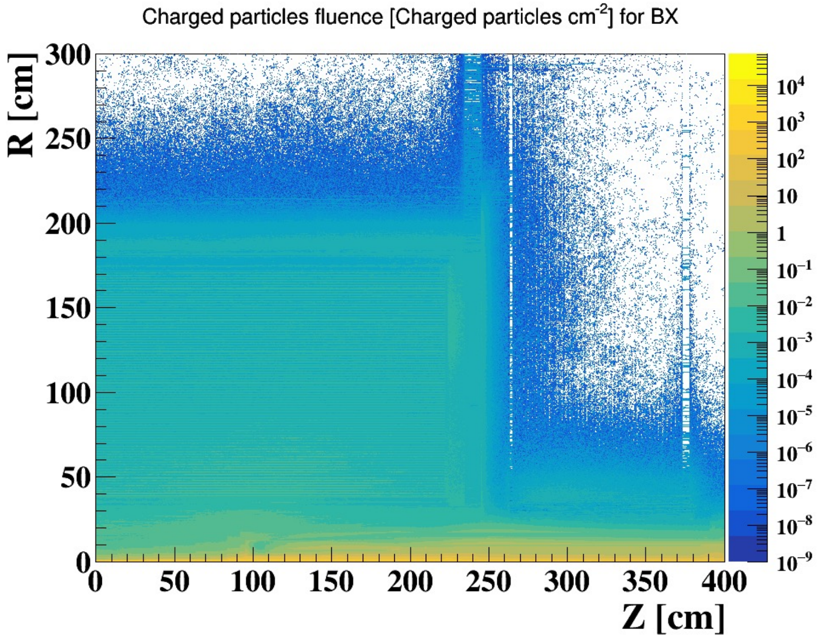
Full Detector Simulation(Higgs)

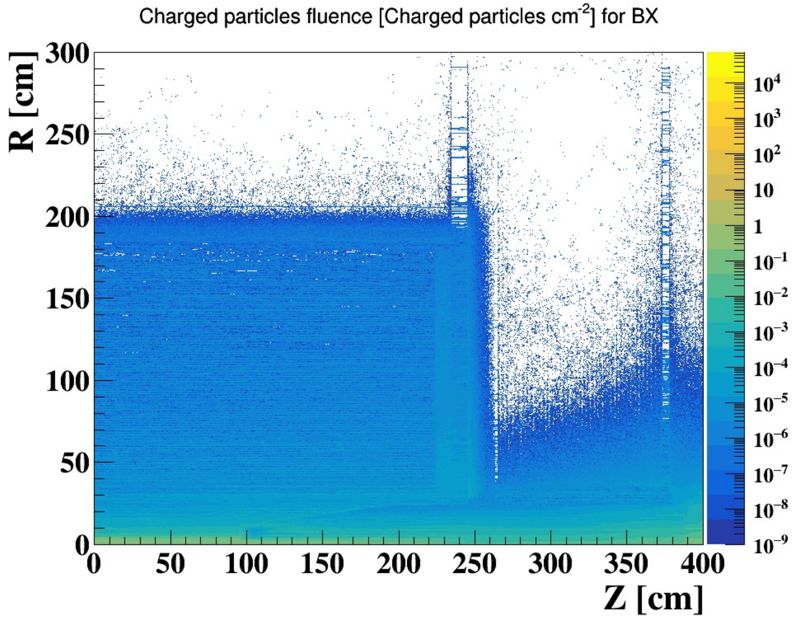


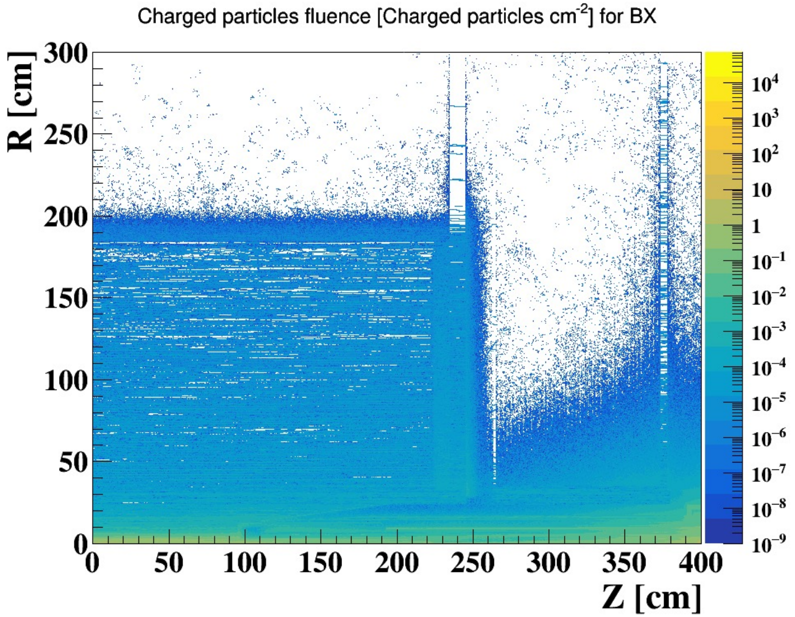


- ECal and Beyond

Full Detector Simulation(Higgs)







Pairs higher than BGB at the same level BTH

Name	Position	Hit/cm²/BX	Hit/cm²/s
VTX	15 mm	~2.3	~3.33e7
SIT	15 cm	~0.01	~14507
TPC	50 cm	~0.005	~7253
Ecal	200 cm	~1e-4	~145
Hcal	220 cm	~2e-6	~2.9

What MDI Study covers now

Accelerator

IP Feedback	Not Covered
BG Simulation	Doing
LumiCal	Doing
HOM absorber	No Need
Vacuum Chamber	Done
SR Masks	Done
QD0/QF1	Doing
Anti-Solenoid	Doing
Cryostats	Doing
BPMs	Doing
Instability&Impendance	Done
Cooling	Done
Shielding	Doing
Assembly&Supporting	Doing
Alignment	Doing
Connecting System	?
Vacuum pumps	Doing
Last Bending Magnet	Done
Collimators	Doing
Control	Not Covered

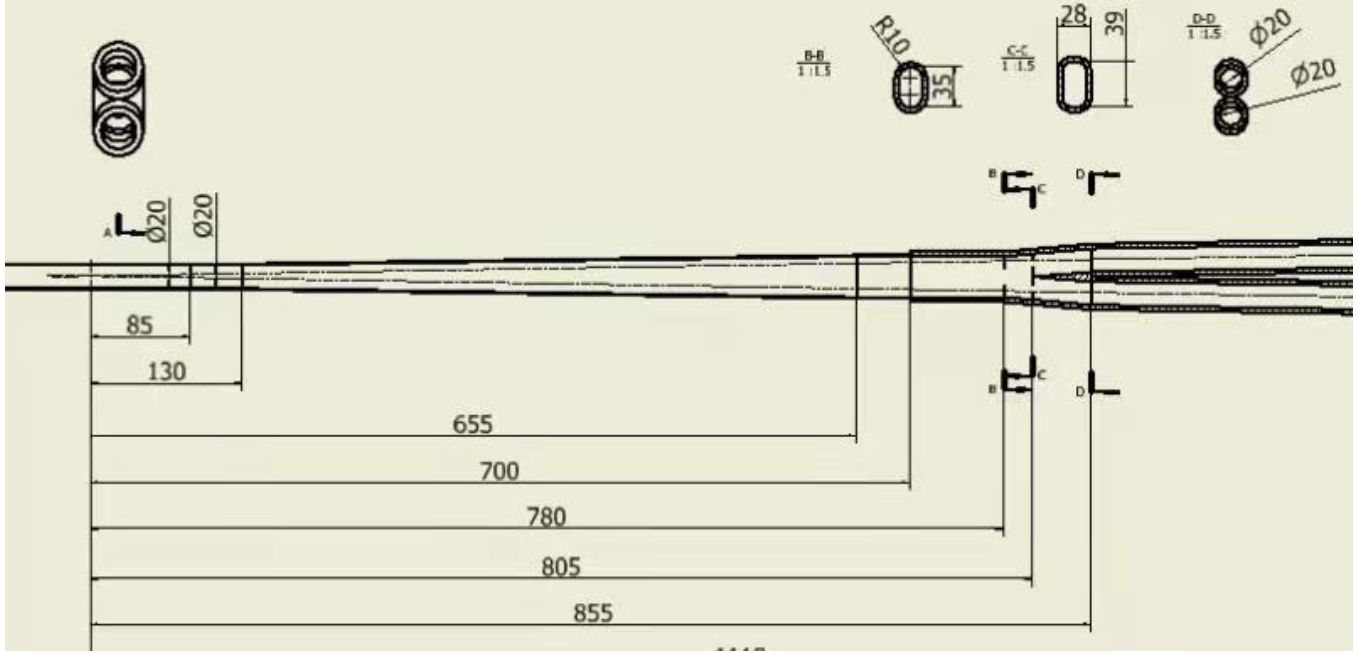
Red means a part of "specific" MDI
Blue means its parameter is relative to MDI

Detector

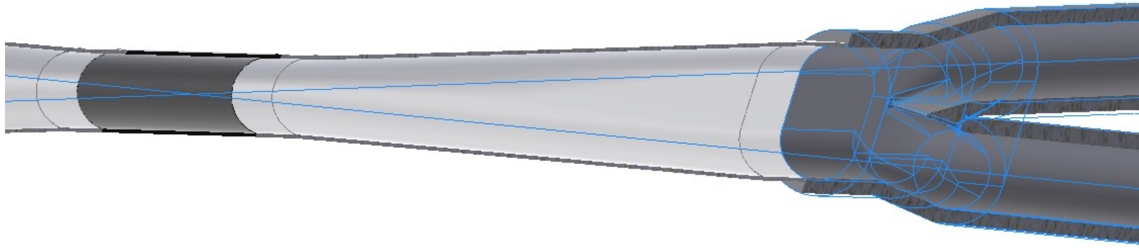
Central Beam Pipe	Done
Vertex Detector	Doing
LumiCal	Doing
Silicon Tracker	Doing
TPC	Doing
Hcal	Doing
Ecal	Doing
Solenoid	Doing, strength Fixed
Yoke	Doing
Muon Detector	Doing
Hall	?
BG Simulation&Shielding	Doing
Software Geometry	Done, check needed
Alignment&Assembly	Doing
Electronics	?
Cryogenic	?
Radiation Protection	Not Covered
Booster	Not Covered

Novel Design– Shrinking to 20mm

- Smaller Be inner diameter would benefit vertex
- Preliminary Design has been performed



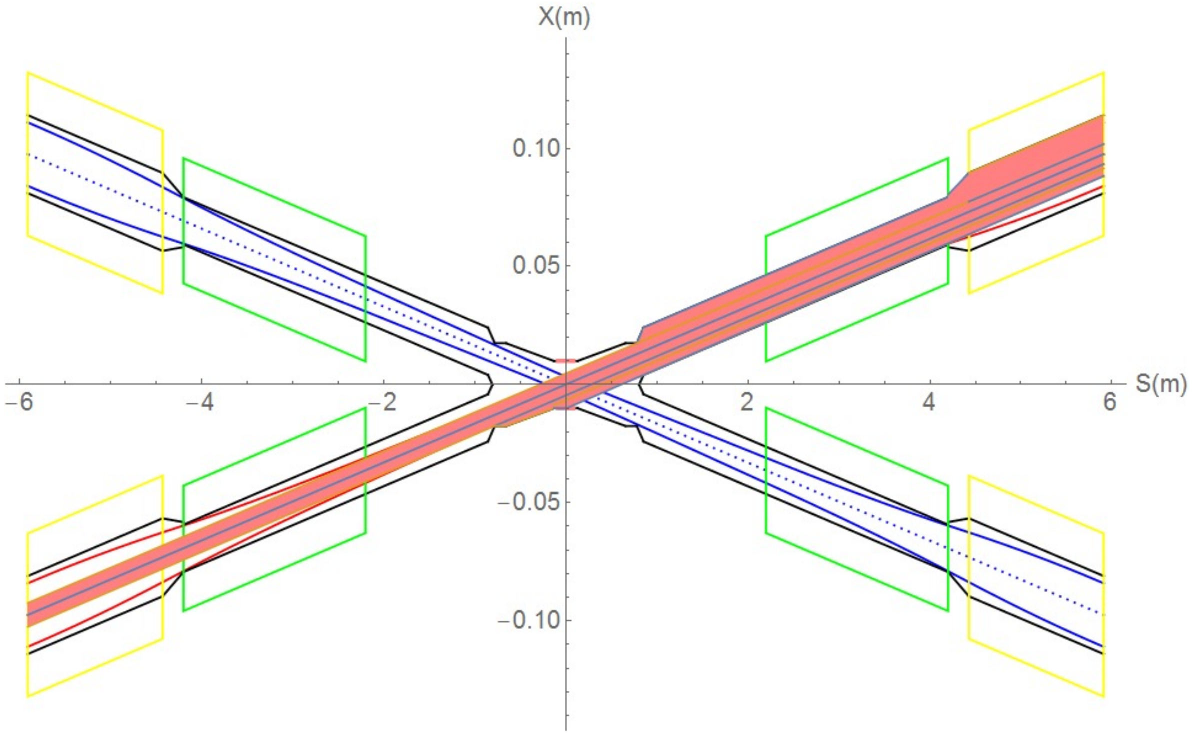
X direction: 20-35-(2-20)mm;
Y direction: 20-20-20mm;



Novel Design - Shrinking to 20mm

- SR would hit Be beam pipe directly in error case
  - SR hitting Be pipe directly in (- 85mm ~ 11.4mm) range, but since instantaneously, heat load is not a problem.
  - SR photons hitting the bellows under the extreme beam conditions, temperature rise ~10C

Region	Material	SR heat load	SR average power density
-85mm ~ 11.4mm	Be	13.74W	41W/cm^2
-130mm ~ -85mm	Al	6.66W	41.1W/cm^2
-780mm ~ -655m	Al	18.3W	40.7W/cm^2



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  - SR hitting Be pipe directly in (- 85mm ~ 11.4mm) range, but since instantaneously, heat load is not a problem.
  - SR photons hitting the bellows under the extreme beam conditions, temperature rise ~10C
  - Several assumptions were taken here:
    - 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.
    - The background of the detector should not be considered under abnormal conditions.
    - The beam orbit deviation will not affect detector operation, since the high background part will be removed when data analysis is carried out.

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Does these acceptable?

Summary

- MDI covers Interaction Region and Beyond. With the MDI map, lots of works are waiting ahead.
- The baseline design of CEPC MDI consist with baseline detector and CDR accelerator parameters is finishing, especially for those “sensitive to beampipe design”.
- The optimization and validation of current design is always needed.
  - The BESIII backgrounds experiment was done. We are still analyzing the results.
- Next steps are to be determined.

What's next?

- Continue finishing current design
  - More detailed & feasible mechanical design
  - More detailed simulation and understanding of the results
  - More realistic model in simulation(fewer lacking sources, better geometry, etc.)
  - More efficiency simulation

- Merging to new design
  - High Luminosity for accelerator?
  - New Detector design?
  - The diameter of central beampipe?

Thank You

Backup

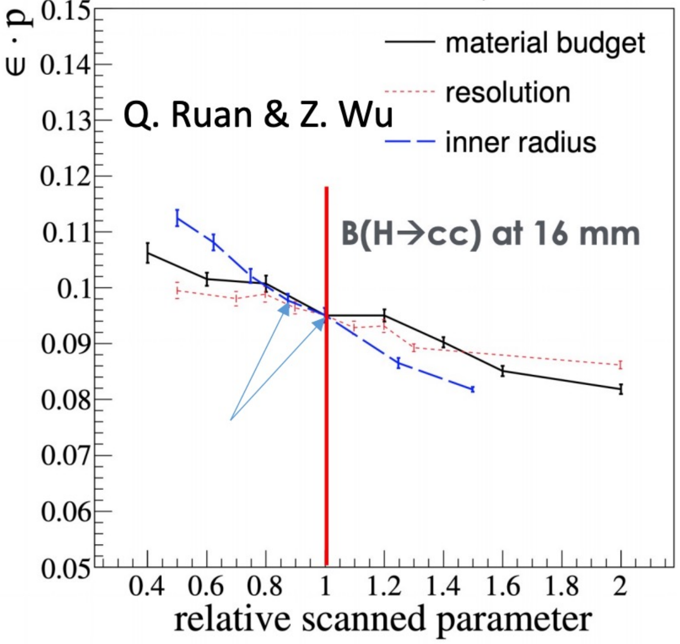
MDI__Accelerator	Person
IP Feedback	J.H. Yue/C.H. Yu/Y.W. Wang
BG Simulation	H.Y. Shi/S. Bai
LumiCal	Suen Hou/Ivanka/Phillipe
HOM absorber	Y.D. Liu/J.Y. Zhai
Vacuum Chamber	H.J. Wang
SR Masks	H.Y. Shi
QD0/QF1	Y.S. Zhu
Anti-Solenoid	Y.S. Zhu
Cryostats	M.F. Xu/T.X. Zhao
BPMs	Y.F. Sui
Instability&Impendance	Y.D. Liu/N. Wang
Cooling	Q. Ji/H.J. Wang
Shielding	H.Y. Shi/Z.J. Ma/S. Bai
Assembly&Supporting	H.J. Wang/Q. Ji
Alignment	X.L. Wang/Q. Ji/H.J. Wang
Connecting System	H.J. Wang
Vacuum pumps	Y.S. Ma
Last Bending Magnet	Y.W. Wang
Collimators	S. Bai/H.J. Wang
Control	G. Li

MDI__Detector	Person
Central Beam Pipe	Q. Ji
Vertex Detector	Z.J. Liang
LumiCal	Suen Hou/Ivanka/Phillipe
Silicon Tracker	H. Fox
TPC	H.R. Qi
Hcal	Y. Liu
Ecal	Y. Liu
Solenoid	F.P. Ning
Yoke	F.P. Ning
Muon Detector	X.L. Wang
Hall	Z.A. Zhu
BG Simulation&Shielding	H.Y. Shi
Software Geometry	C.D. Fu
Alignment&Assembly	Q. Ji/H.J. Wang/X.L. Wang
Electronics	W. Wei
Cryogenic	T.X. Zhao
Radiation Protection	Z.J. Ma
Booster	D. Wang

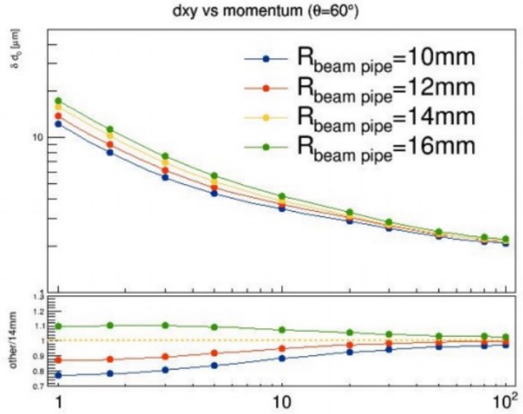
Physics Gains for 20mm Be

- First estimates made with fast simulation and scaling

$$\frac{\delta_\mu}{\mu} \propto \frac{\sqrt{S+B}}{S} \propto \frac{1}{\sqrt{\epsilon \cdot p}}$$



$$\sigma_{d_0}^2 = \sigma_{geom}^2 + \sigma_{MS}^2$$
$$= \left(\frac{\sigma_1 r_2}{r_2 - r_1}\right)^2 + \left(\frac{\sigma_2 r_1}{r_2 - r_1}\right)^2 + \sum_{j=1}^{n_{scatt}} (R_j \Delta\Theta_j)^2$$



H. Zeng

- Implement the geometry in simulation and run a full analysis to estimate the physics gains

G. Li