CEPC MDI Study Status

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On behalf of the CEPC MDI Study Group

The 2021 International Workshop on CEPC

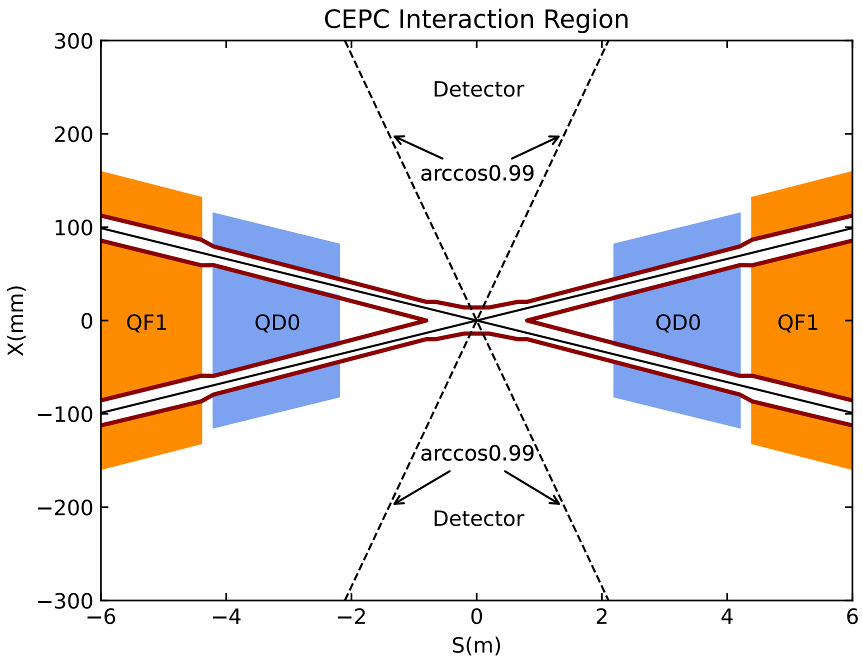
2021.11.11, Nanjing(Zoom)

Outline

- Introduction
  - What are the inputs of current MDI Study?
- Map of MDI Study
  - What belongs to MDI?
- Current Study Status
  - Status of baseline design
  - Engineering effort
  - Novel design proposal
- Summary & Outlook

Introduction

- MDI stands for "Machine Detector Interface"
  - Interaction Region and beyond
  - 2 IPs
  - 33mrad Crossing angle
- Flexible optics design
  - Common Layout in IR for all energies
- For CEPC CDR, the interaction region is ± 6 m from the IP
- High Luminosity, low background impact, low error
- Concerning engineering:
  - Stable and easy to install
  - Easy to replace/repair

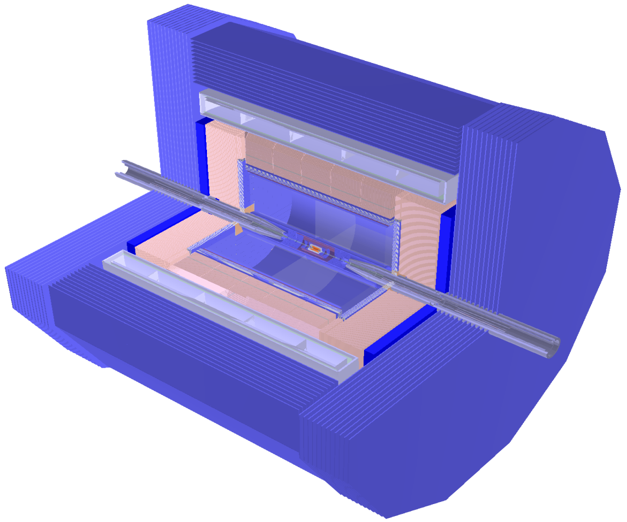


Introduction – Accelerator Parameters

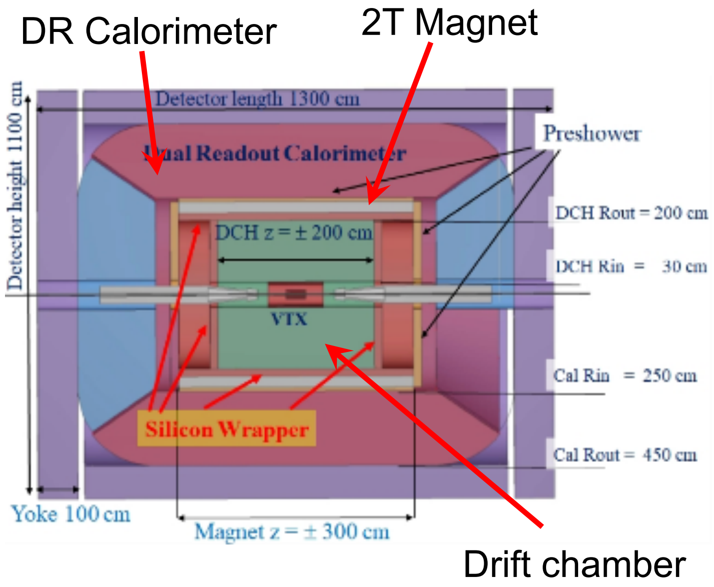
	CDR Parameters				High Luminosity Parameters			
	Higgs	**W**	**Z（3T）**	**Z（2T）**	**tt**	**Higgs**	**W**	**Z**
Number of IPs	2				2			
Beam energy (GeV)	120	80	45.5		180	120	80	45.5
Circumference (km)	100				100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036		8.53	1.73	0.34	0.036
Half Crossing 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

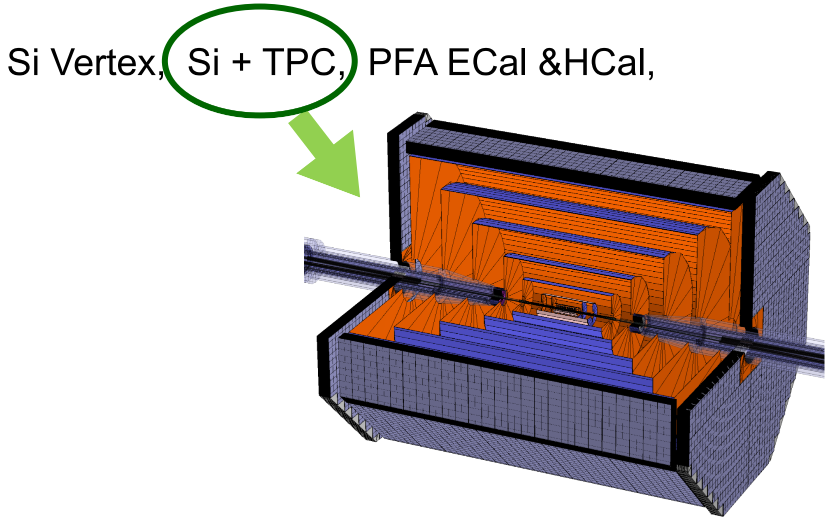
Particle Flow Approach
(ILD-like)



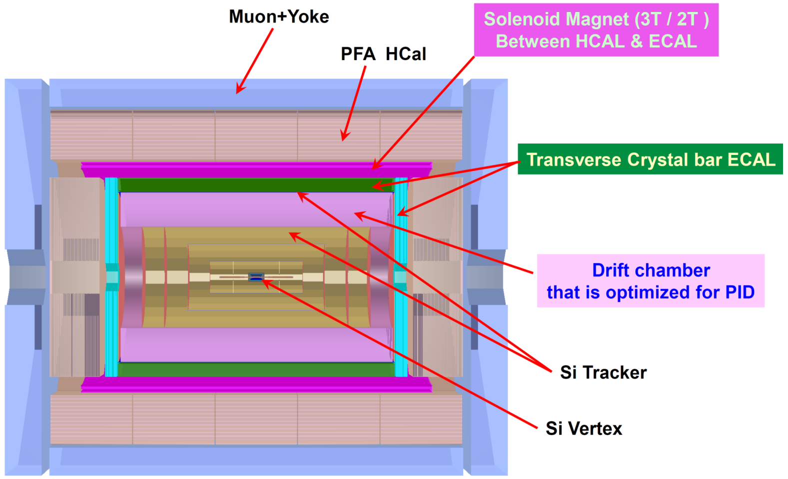
IDEA concept
(also proposed for FCC-ee)



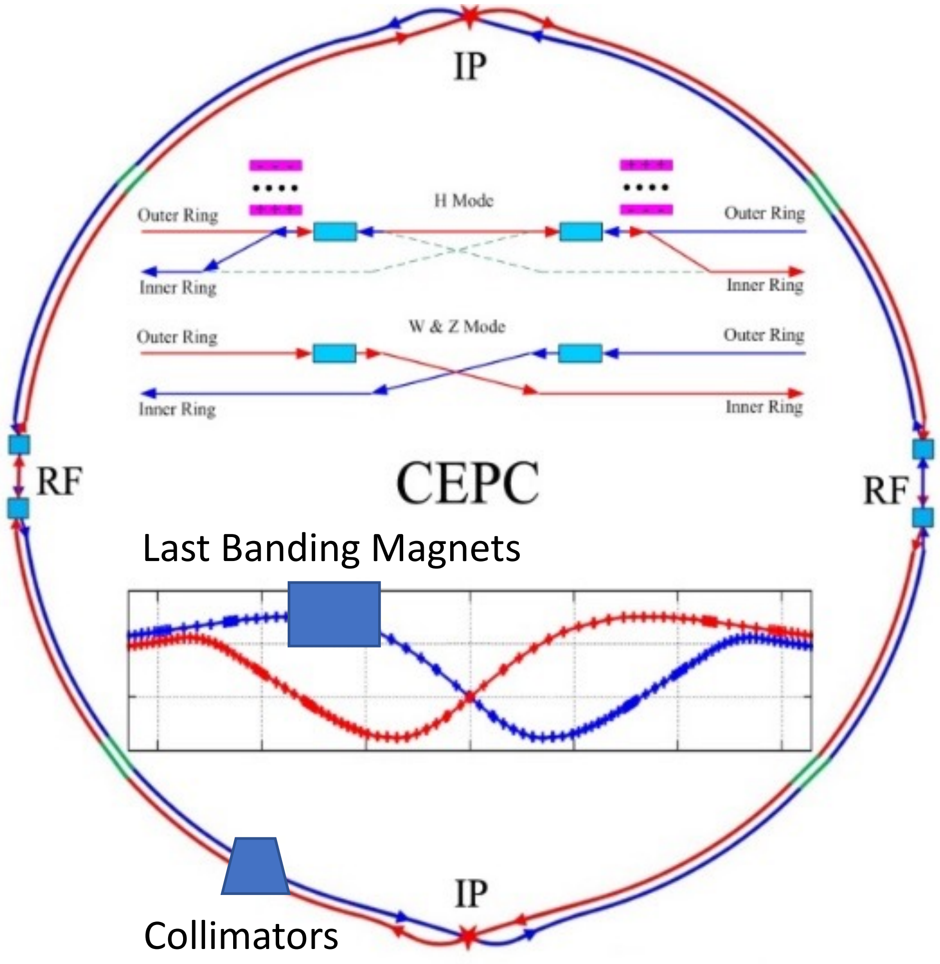
Full Silicon Tracker
(FST) concept



4th 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)

	Higgs	*W*	*Z (2T)*
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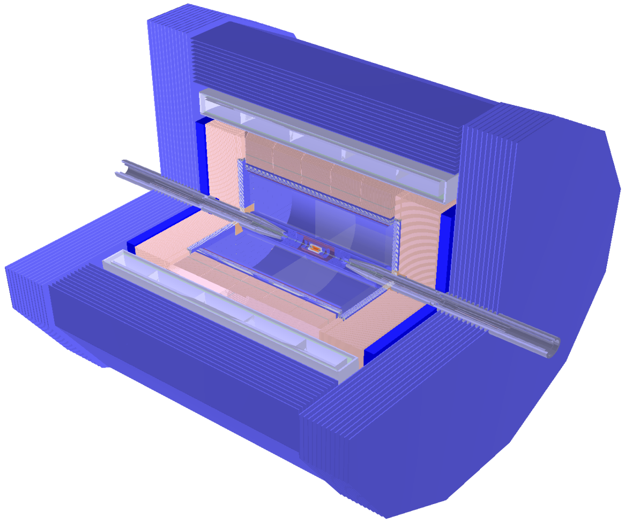
Baseline Detector



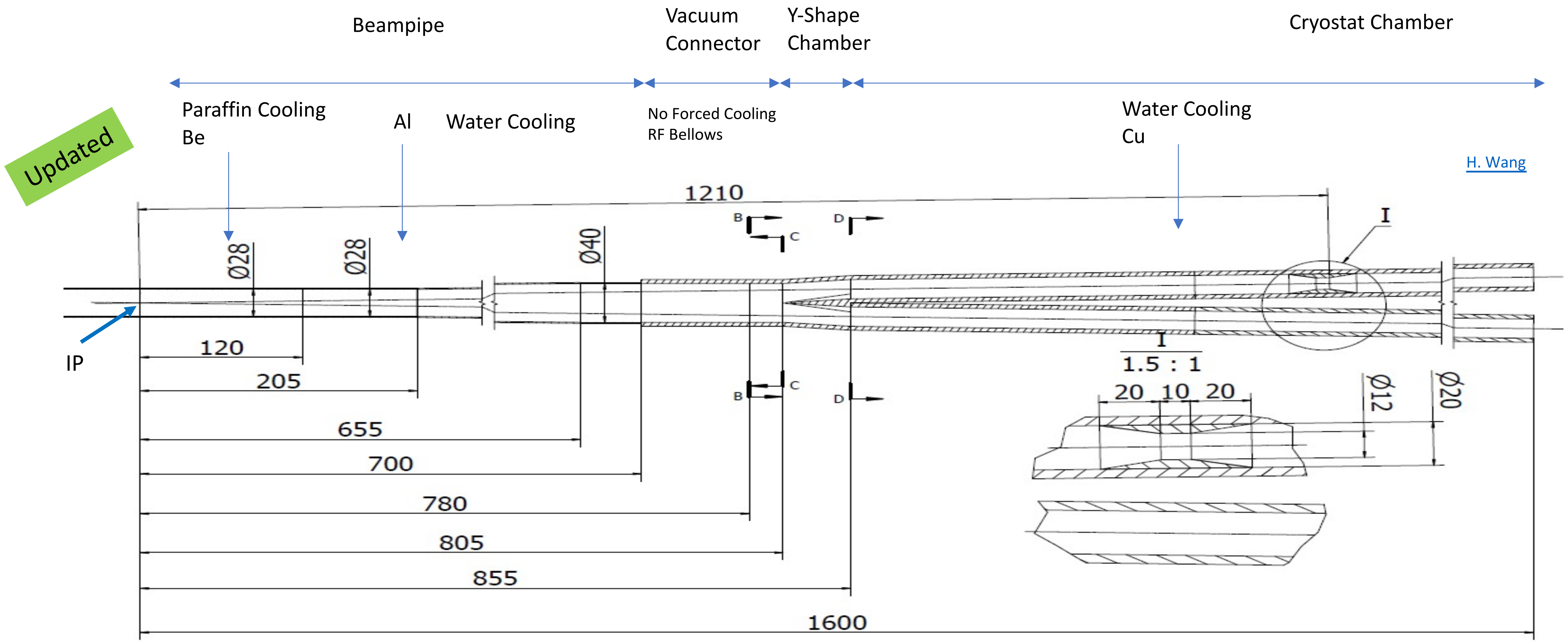
The MDI Table

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	$\pm$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					$\pm$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								

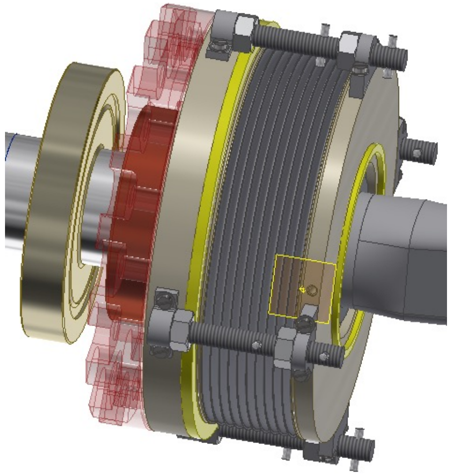
The latest beampipe design

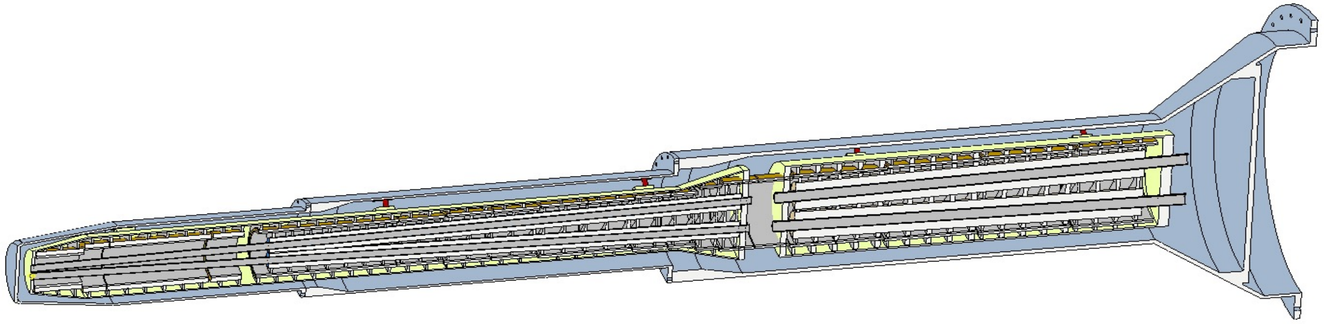
Nearly 20 versions tried in since last summer



The latest design

- Physical Design Improved & Engineering efforts:
  - Collimators
  - Masks
  - LumiCal
- Engineering efforts:
  - RVC
  - Magnets
  - Cryostat





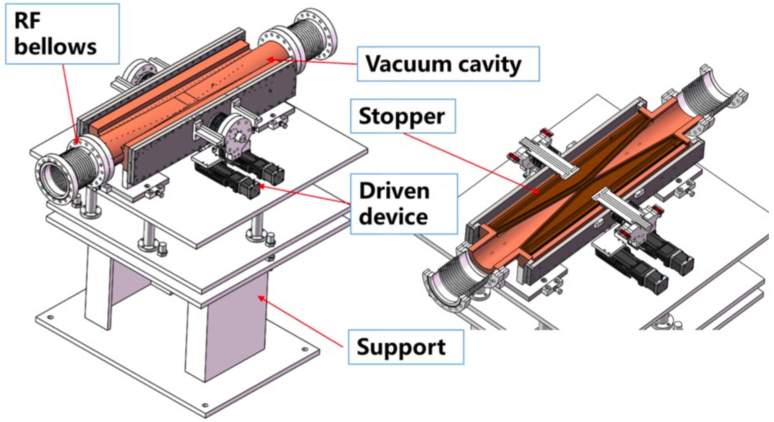
Refer to [Haijing's Talk in the Accelerator Session](), and Yingshun's Talk later today.

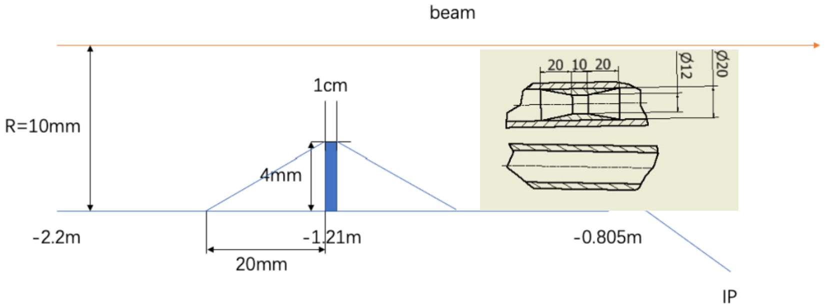
Collimators & Masks

Refer to [Haijing's Talk in Accelerator Session]

- Movable Collimators & Fixed Masks are indispensable for BG suppressing.
- 4 sets of BG 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.
- Fixed Collimators are also needed for Machine Protection Purpose.

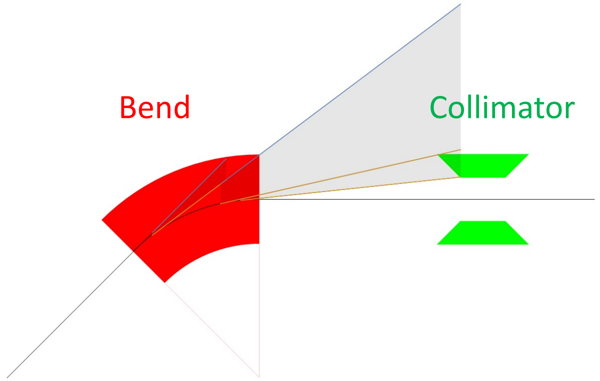
H. Wang

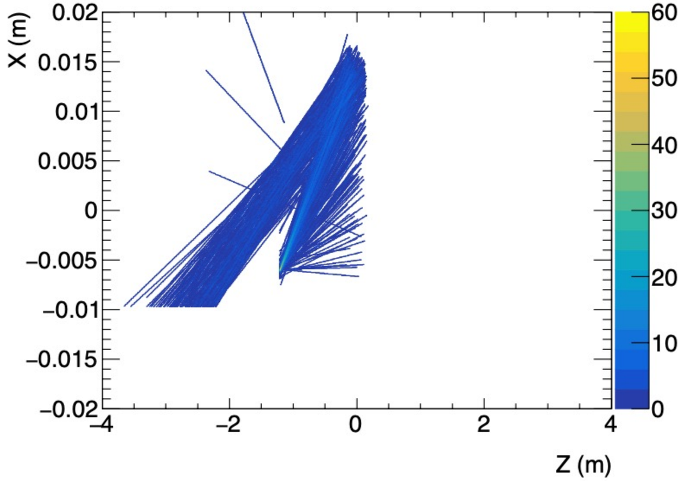




Name	Location	From IP
APTX1	D1I.1897	2139.06
APTX2	D1I.1894	2207.63
APTX3	D1O.10	1832.52
APTX4	D1O.14	1901.09

S. Bai

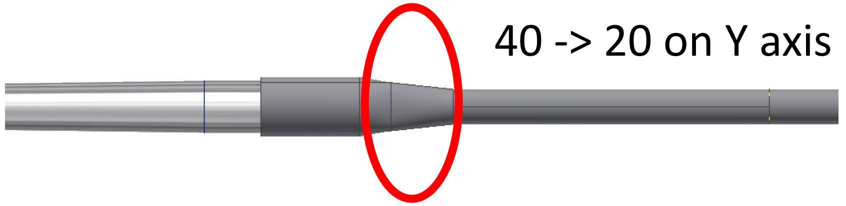


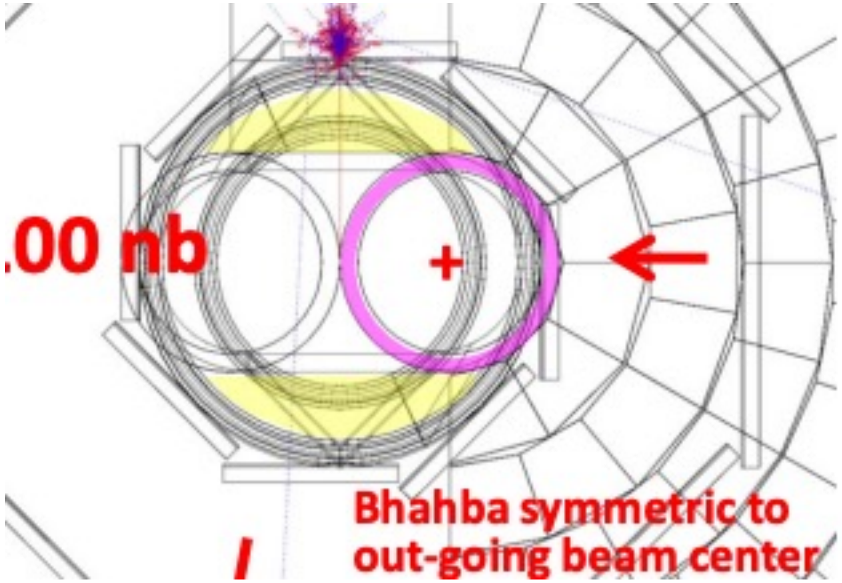


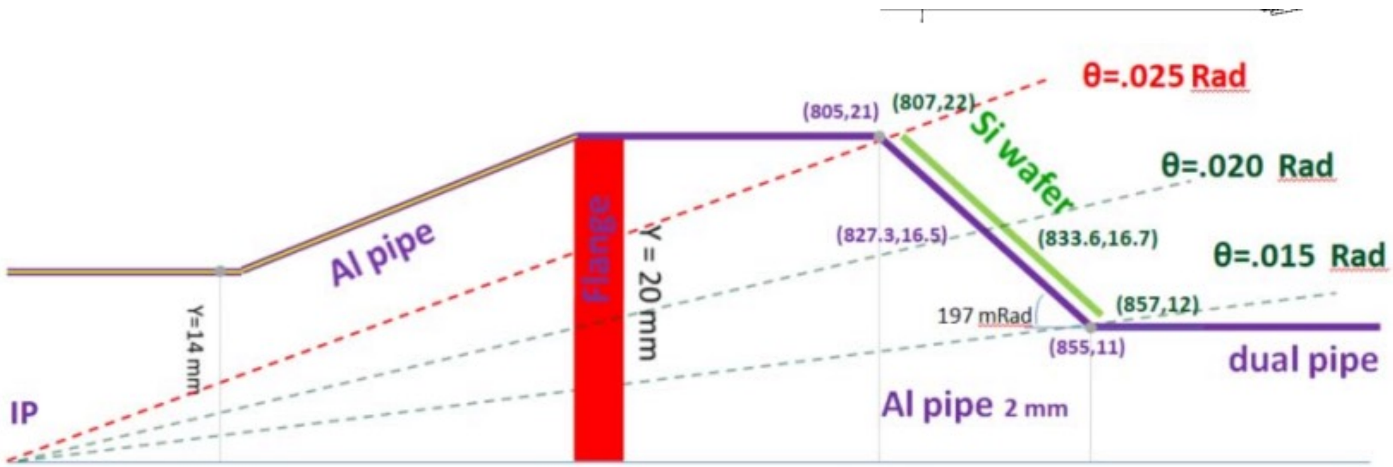
LumiCal

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







“Safety Check”

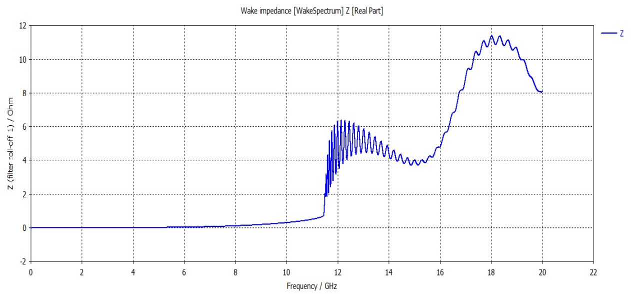
- Thermal Analysis(including impendence)
  - Source
    - HOM Heating
    - Synchrotron Radiation
    - Other Backgrounds(Negligible)
- Mechanical Calculation and Optimization
- Backgrounds Estimation
  - Full Detector Simulation

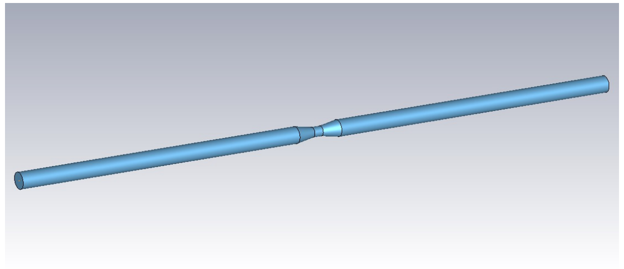
HOM & Impendence

Refer to Yudong's Talk in Accelerator Session

- 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





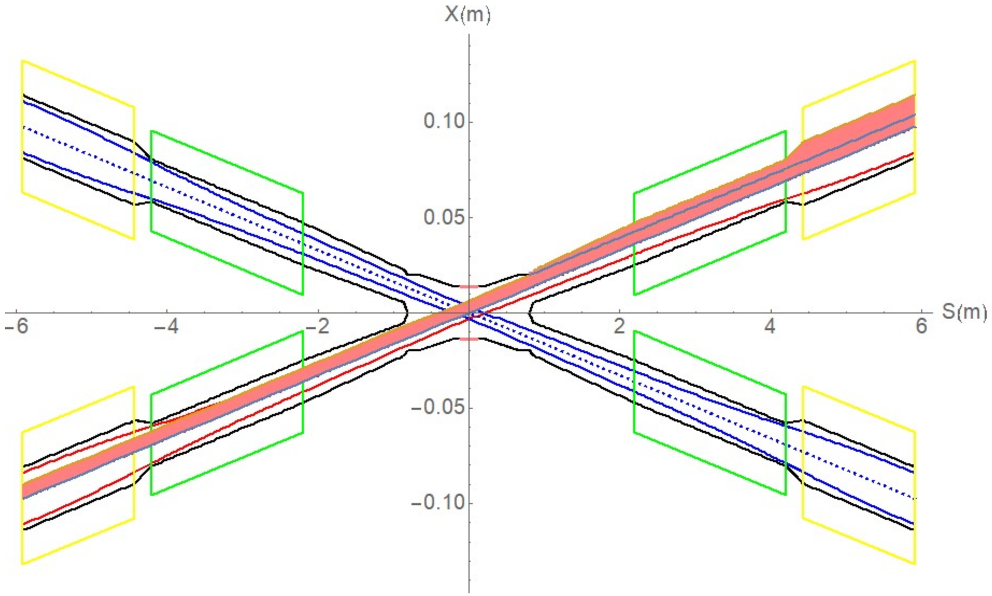
Loss factor(V/pc)	Power @Higgs	Power @W	Power @Z
$8.69*10^{-4}$	0.36 w	1.47 w	5.13w

Synchrotron Radiation

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

Revised beam pipe design to achieve

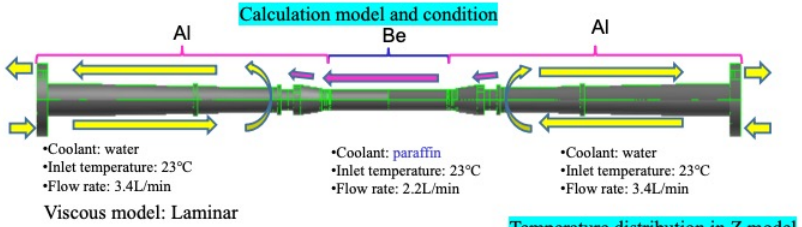
No direct SR photons hitting the central beam pipe except the extreme beam conditions (e.g. beam off orbit due to magnet errors, $\pm 5\ mm, \pm 2\ mrad$)

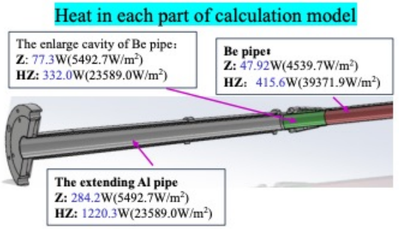


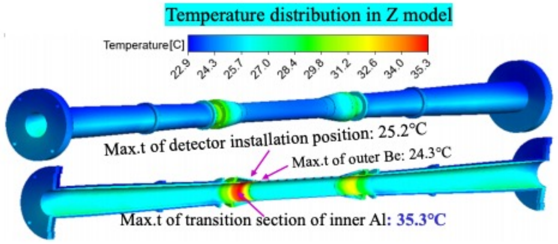
	Power Deposition	Average Power Density
0.805~0.855m	16W	88.9W/cm^2
0.855~2.2m	12.3W	2.54W/cm^2
QD0(2.2m~4.2m)	2.79W	0.39W/cm^2
QD0~QF1(4.2~4.43m)	36.1W	43.6W/cm^2
QF1(4.43m~5.91m)	3W	0.56W/cm^2

Thermal Analysis

Refer to Junsong's talk



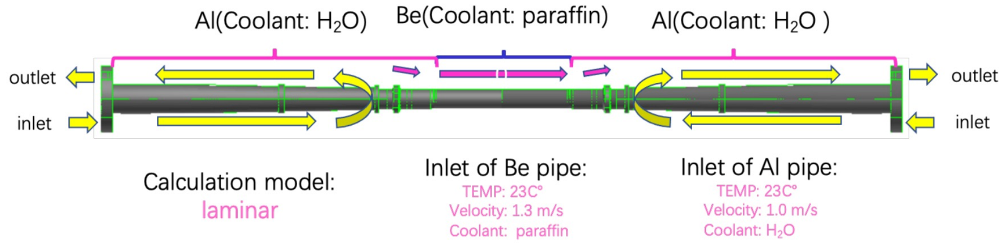


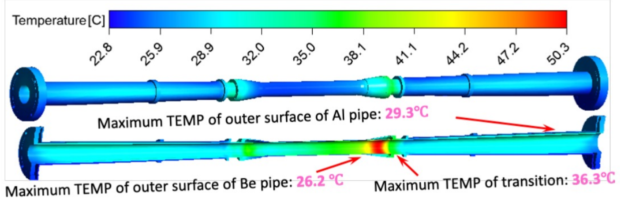


paraffin: Δp=19.8kPa, Δt=3.1°C
water: Δp=14.8kPa, Δt= 1.2°C

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





Temperature rise:
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Transition: 13.3 ℃
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Pressure drop:
Be pipe : 19.8 kPa
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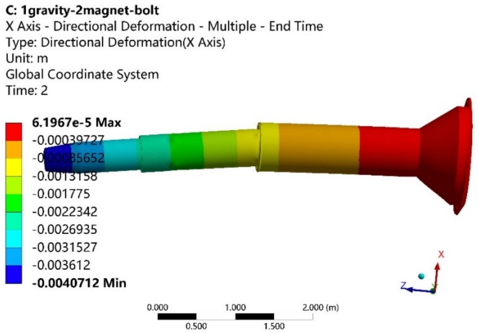
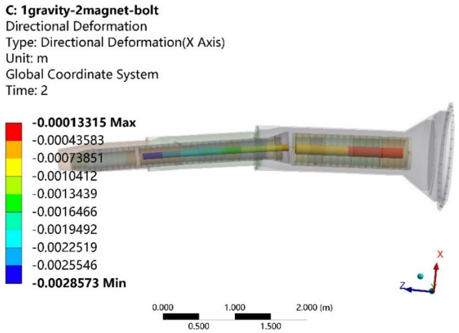
Conclusion:
Temperature rise and pressure drop within safe range

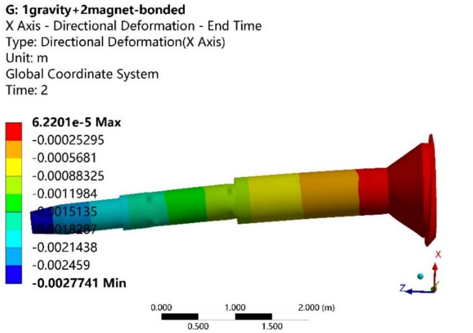
Mechanical Calculation and Optimization

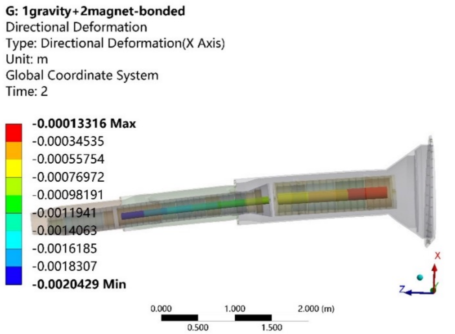
Refer to [Haijing's Talk in Accelerator Session] *Refer to Junsong's talk*

Deformation Calculation

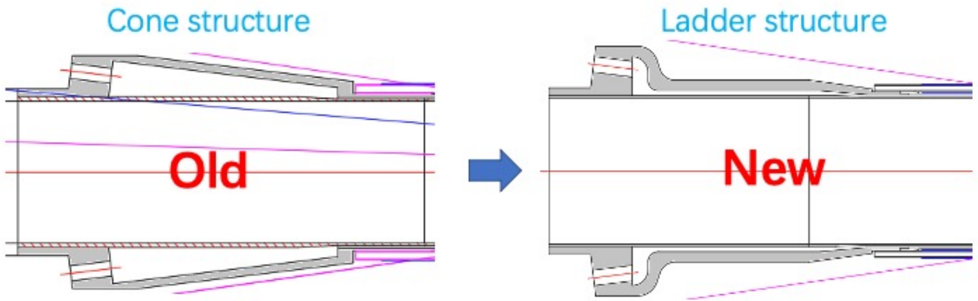




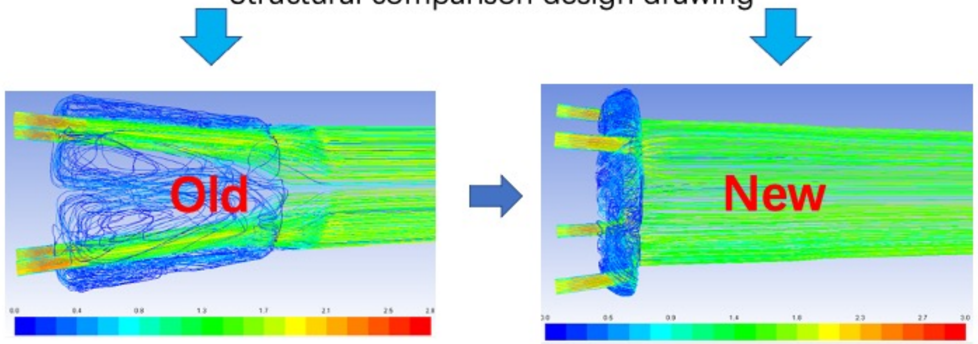




Detailed Beampipe Design



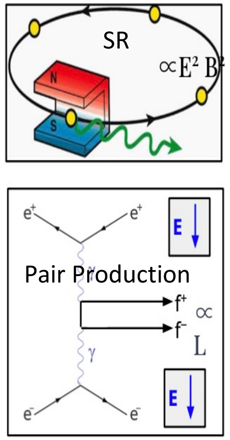
Structural comparison design drawing



Streamline comparison chart

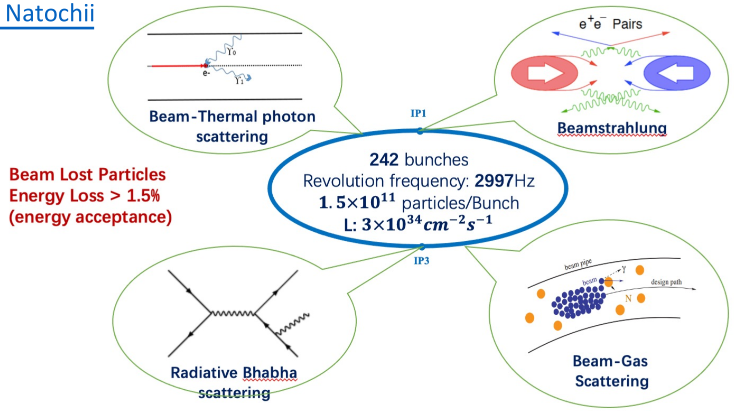
Background Estimation

- Treat every background separately
- Whole-Ring generation for single beam BGs
- Ideal Beam for all
  - No orbit errors
  - No beam tail
- Multi-turn tracking
  - Using built-in LOSSMAP with one step ahead output
  - SR emitting on
  - RF on
  - No solenoid
- Next:
  - 2 IR per ring
  - Magnet errors
  - Integrating to CEPCSW
  - Injection BG



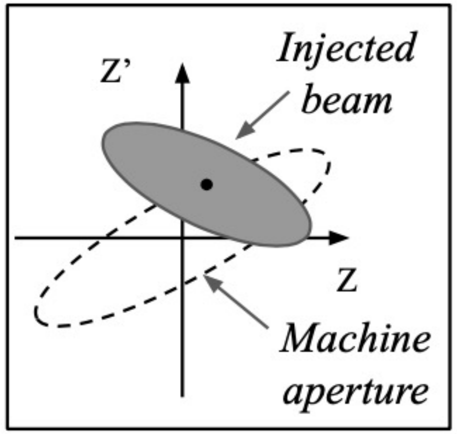
A. Natochii

Photon BG



Beam Loss BG

A. Natochii



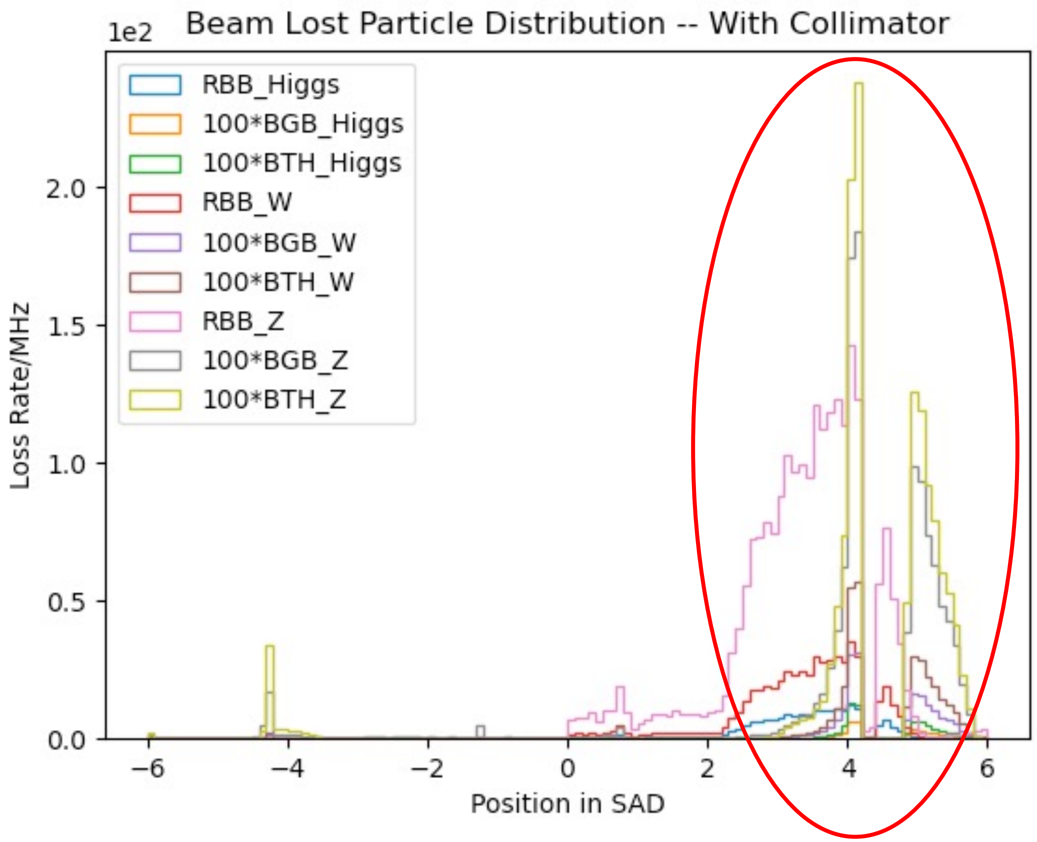
Injection BG

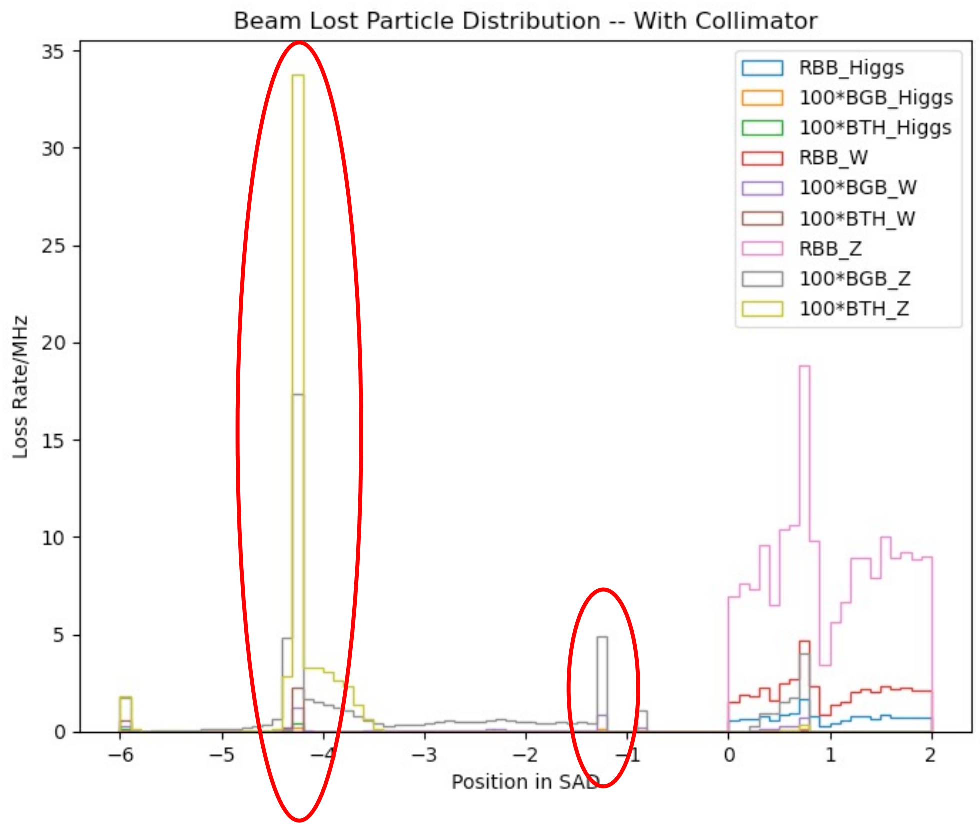
Updated

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

LOSSMAP in IR(CDR, baseline)

- Significant Loss in Downstream quadrupoles.
- The main reason of upstream hotspot is the decrease of beam pipe radius.





Detector Impact(CDR, baseline)

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

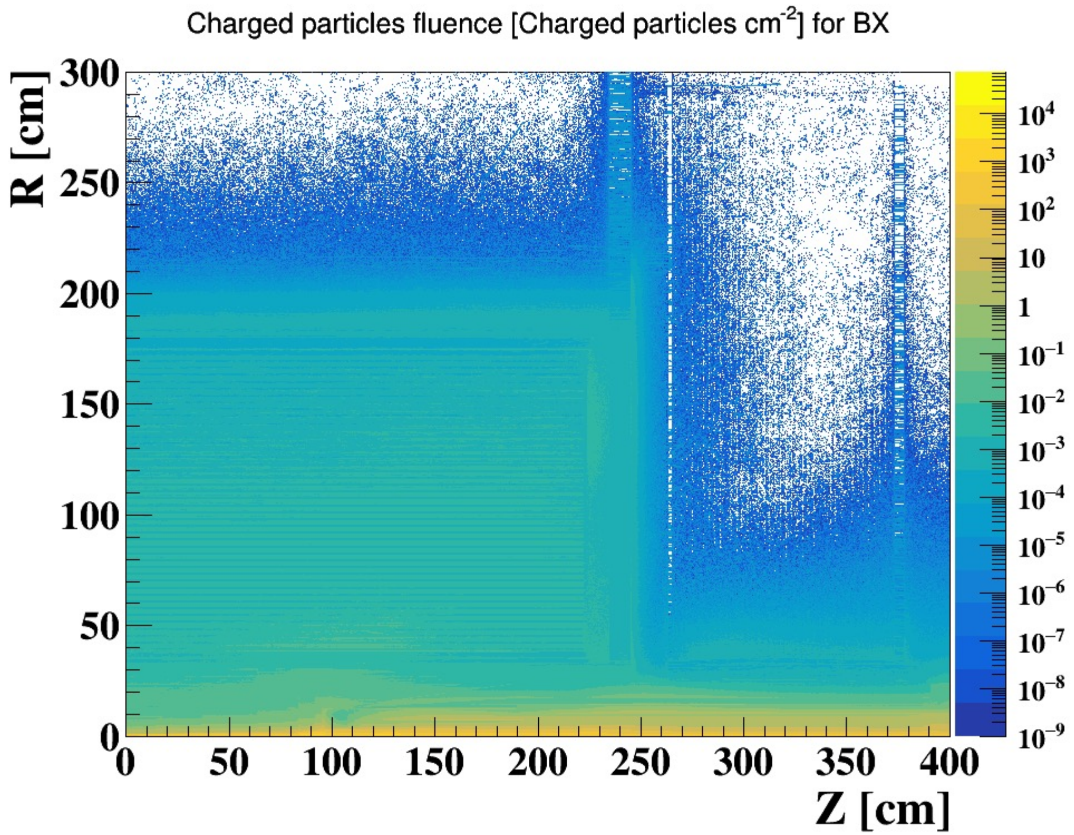
	Higgs	W	Z
Hit Number	~320	~28	<1

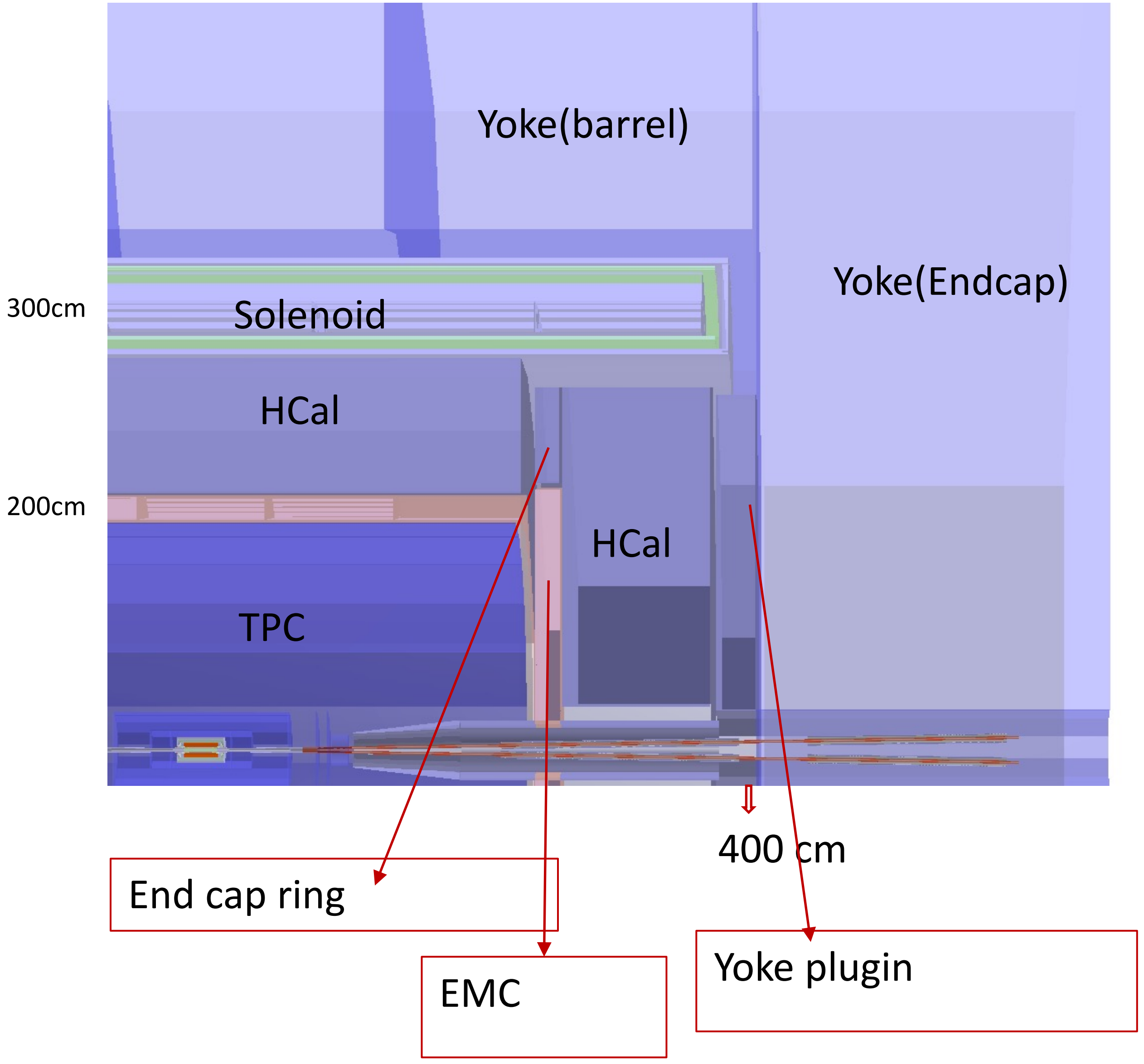
- Preliminary results on 1st layer of vertex. Safety factor of 10 applied.

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
Beam Thermal Photon	0.1	0.1	0.03	0.07	0.3	0.8	0.2	0.7	1.9
Total	2.3	1.7	0.63	0.93	3.7	10.5	2.2	8.1	23.6
Lifetime	-			31.21			70.7		
Total_oCDR	2.4	2.3	0.25	0.93	2.9	3.4	2.1	5.5	6.2

How to estimate the uncertainty?

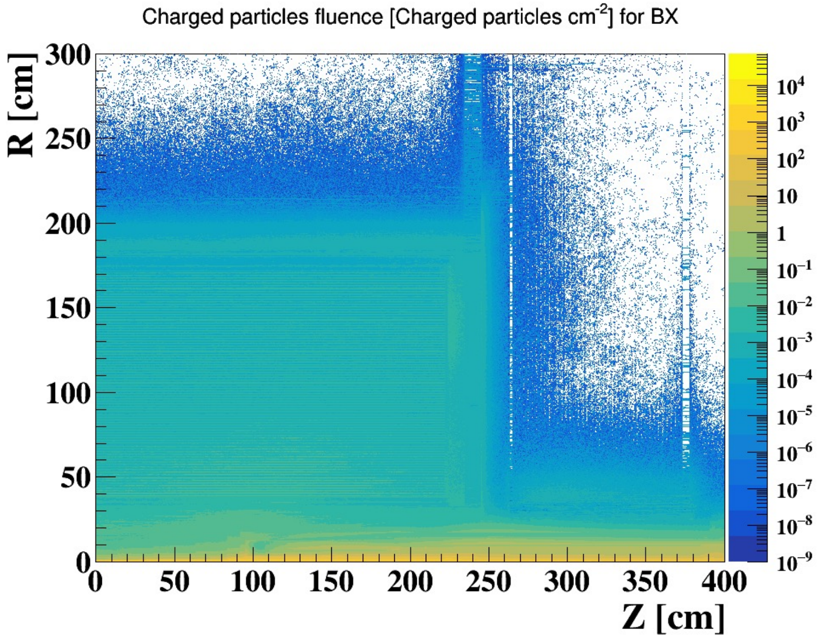
Full Detector Simulation(CDR, Higgs)

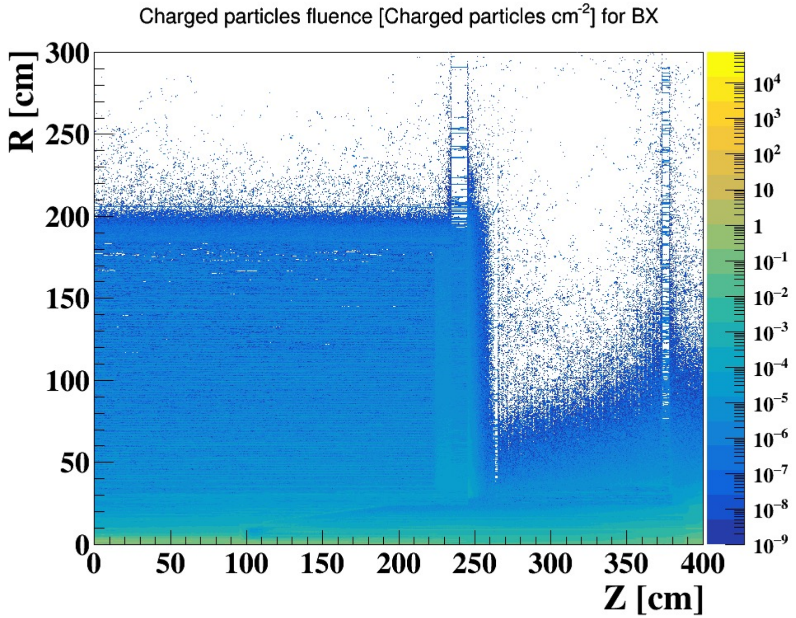


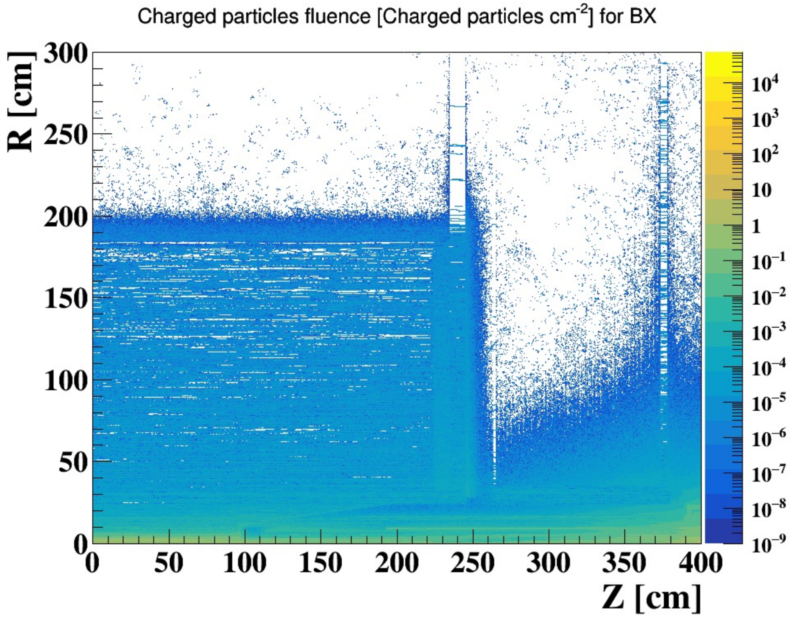


- ECal and Beyond

Full Detector Simulation(CDR, Higgs)







Pairs higher than BGB at the same level BTH

Name	Position	Hit/cm^2/BX	Hit/cm^2/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

Red means a part of “specific” MDI , Blue means its parameter is relative to MDI, while Black means it would affect by MDI

Accelerator

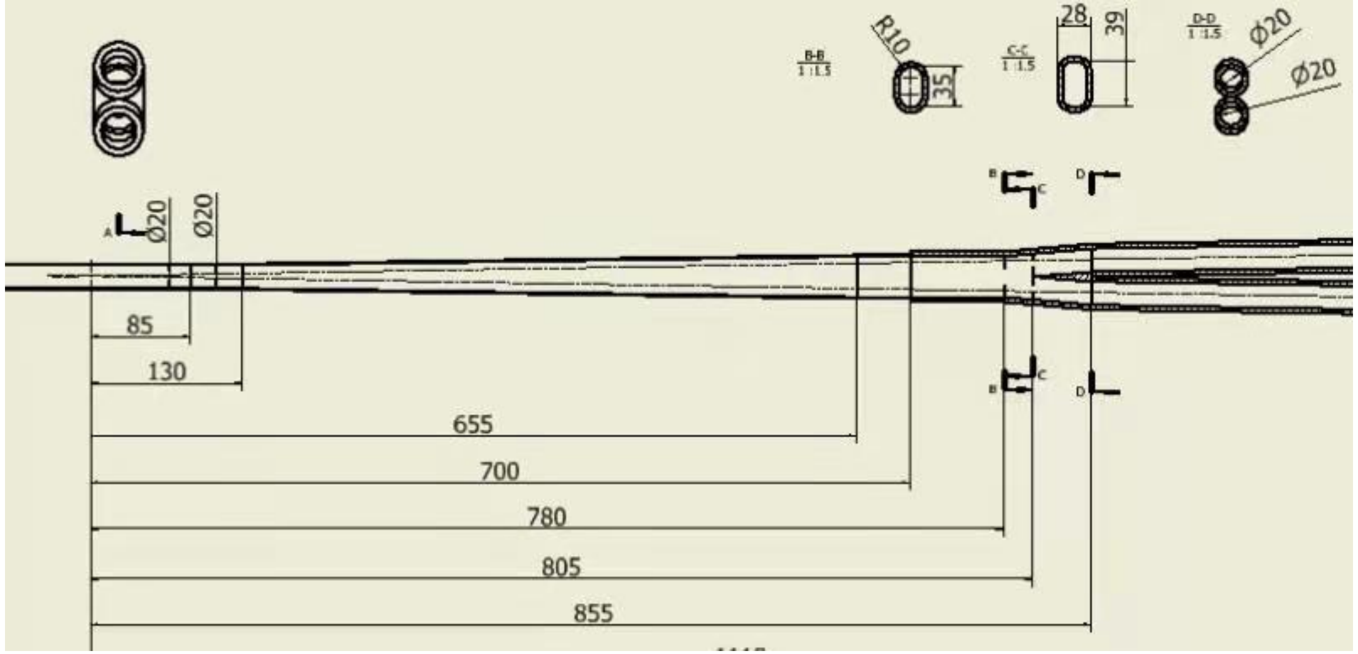
IP Feedback	Not Covered
BG Simulation	Doing
LumiCal	Doing
HOM absorber	No Need
Vacuum Chamber	Done
SR Masks	Done
QD0/QF1	Doing
Anti-Solenoid	Doing
Cryostats	Doing
BPMs	Doing
Instability&Impendance	Done
Cooling	Done
Shielding	Doing
Assembly&Supporting	Doing
Alignment	Doing
Connecting System	Doing
Vacuum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

Detector

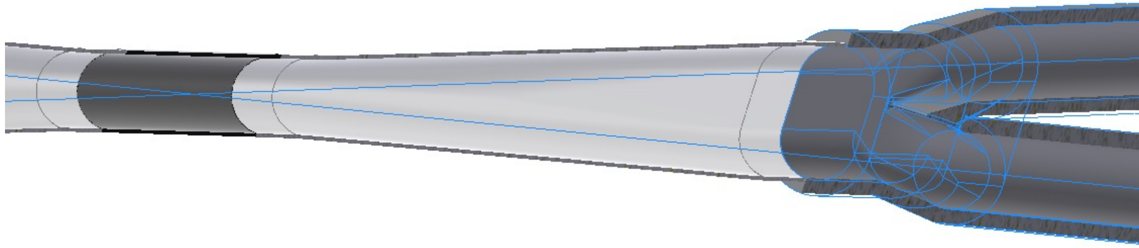
Central Beam Pipe	Done
Vertex Detector	Doing
LumiCal	Doing
Silicon Tracker	Doing
TPC	Doing
Hcal	Doing
Ecal	Doing
Solenoid	Doing, strength Fixed
Yoke	Doing
Muon Detector	Doing
Hall	Doing
BG Simulation&Shielding	Doing
Software Geometry	Done, check needed
Alignment&Assembly	Doing
Electronics	Doing
Cryogenic	Doing
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;

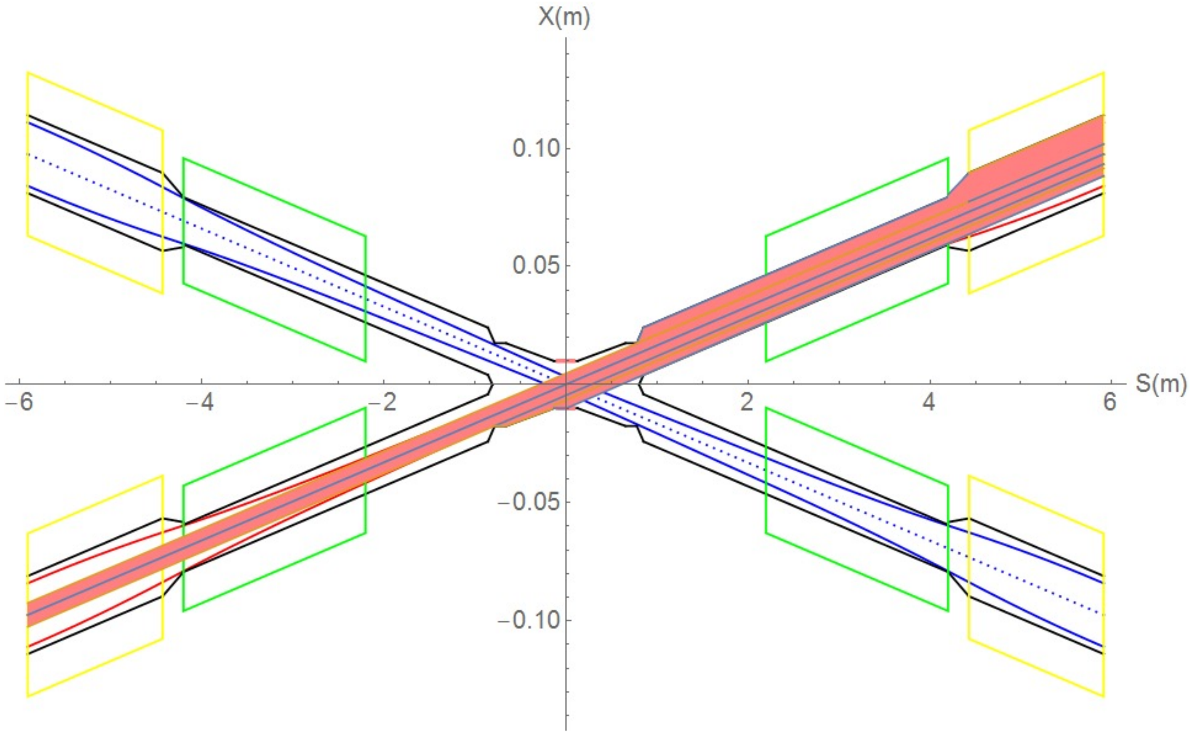


Novel Design - Shrinking to 20mm

- 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

S. Bai

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



Summary & Outlook

- 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 on going:
  - The physical design of most components or sub-systems is nearly finished.
  - The consistency of all designs need to be checked.
  - The known issues of current design need to be listed. Some are urgent to be solved with this design, some could be put into next version.
- The optimization and validation of current design is always needed.
  - The BESIII backgrounds experiment was done. We are still analyzing the results.
- The work based on new version of accelerator and detector(also new energy) would be started soon.

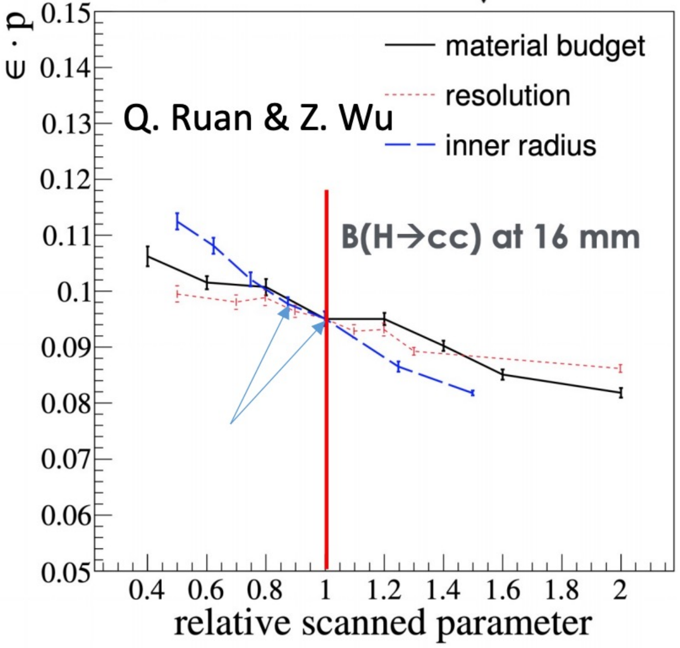
Thank You

Backup

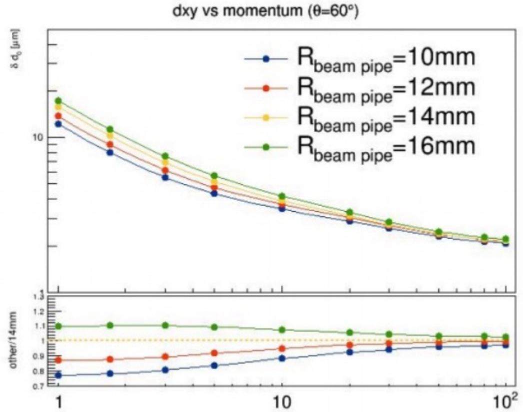
Physics Gains for 20mm Be

- 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

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