CEPC MDI Study Status

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On behalf of the CEPC MDI Working Group

Joint Workshop of the CEPC Physics, Software and New Detector Concept in 2022

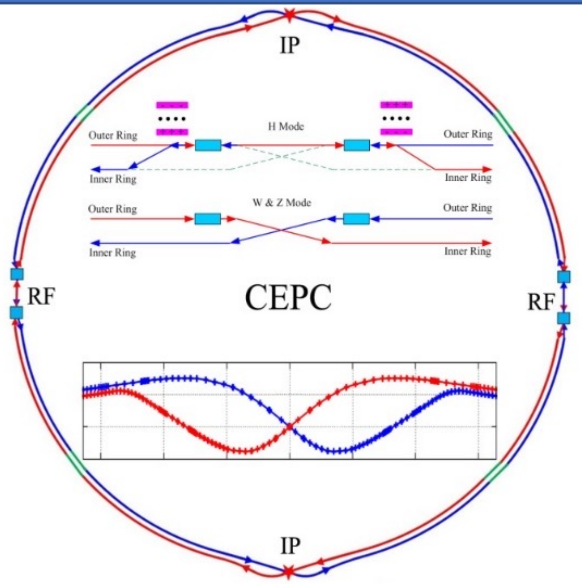
2022.05.23, Beijing(Zoom)

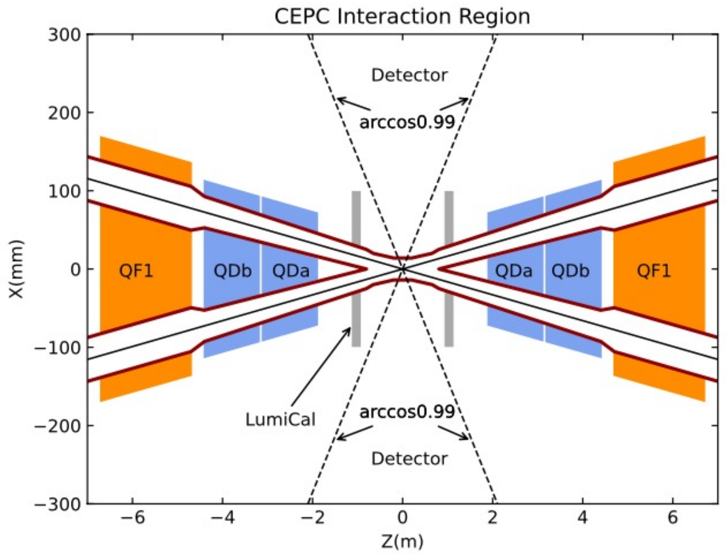
Outline

- Introduction
- Current Study Status
  - Physics Design
    - Layout/Components/Parameters
    - Heat Deposition/Radiation Levels
  - Engineering effort
    - Mechanical Design of each components(beampipe, cryostat, connector…etc)
    - Integration/Installation Scheme(Refer to Songwen’s talk later today)
- Summary & Outlook

Introduction

- MDI stands for ”Machine Detector Interface”
  - Interaction Region and other components
  - 2 IPs
  - 33mrad Crossing angle
- Flexible optics design
  - Common Layout in IR for all energies
  - High Luminosity, low background impact, low error
  - Stable and easy to install, replace/repair
- For CEPC TDR, the interaction region is ± 7 m from the IP





Inputs – Accelerator Parameters

2018 CDR Baseline Design

	Higgs	W	Z (3T)	Z (2T)
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5 × 2			
Piwinski angle	3.48	7.0	23.8	
Particles /bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number	242	1524	12000 (10% gap)	
Bunch spacing (ns)	680	210	25	
Beam current (mA)	17.4	87.9	461.0	
Synch. radiation power (MW)	30	30	16.5	
Bending radius (km)	10.7			
Momentum compaction (10^{-5})	1.11			
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
Emittance x/y (nm)	1.21/0.0024	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.06	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.018/0.109	0.013/0.123	0.004/0.06	0.004/0.079
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz)	650			
Harmonic number	216816			
Natural bunch length σ_z (mm)	2.72	2.98	[illegible]	[illegible]
Bunch length σ_z (mm)	4.4	[illegible]	[illegible]	[illegible]
Damping time $\tau_x/\tau_y/\tau_E$ (ms)	[illegible]	[illegible]	849.5/849.5/425.0	
Natural Chromaticity	[illegible]	[illegible]/-1161	-491/-1161	-513/-1594
Betatr[illegible]	363.10 / 365.22			
S[illegible]	0.065	0.040	0.028	
H[illegible] (2 cell) (kw)	0.46	0.75	1.94	
Natural energy spread (%)	0.100	0.066	0.038	
Energy spread (%)	0.134	0.098	0.080	
Energy acceptance requirement (%)	1.35	0.90	0.49	
Energy acceptance by RF (%)	2.06	1.47	1.70	
Photon number due to beamstrahlung	0.082	0.050	0.023	
Beamstruhlung lifetime /quantum lifetime† (min)	80/80	>400		
Lifetime (hour)	0.43	1.4	4.6	2.5
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP (10^{34} cm^{-2}s^{-1})	3	10	17	32

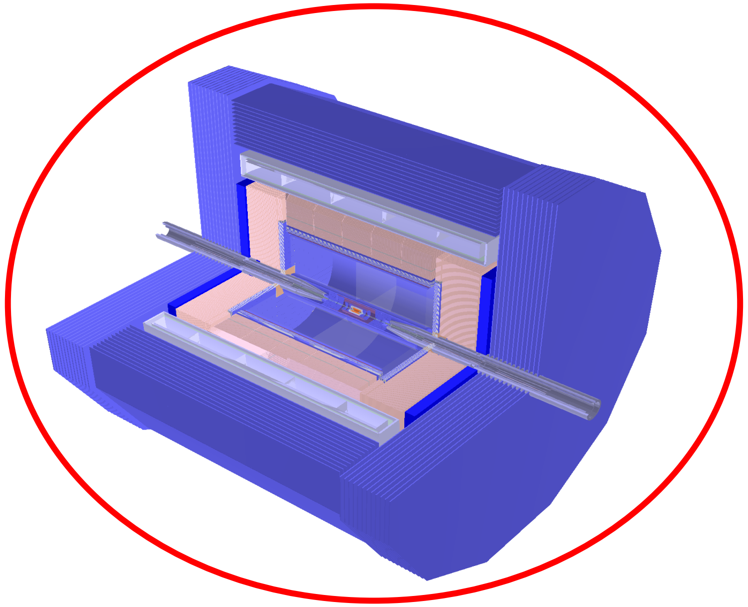
† include beam-beam simulation and real lattice

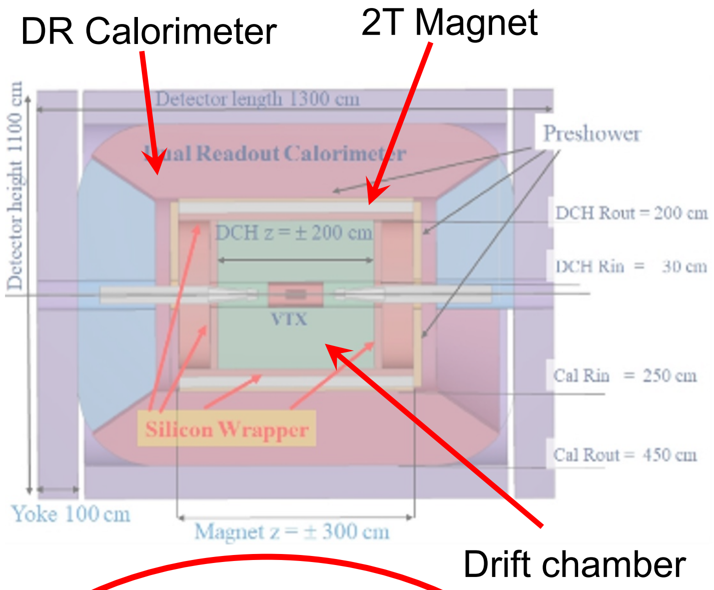
2021 Improved Design

	ttbar	Higgs	W	Z
Number of Ips		2		
Circumference [km]		100.0		
SR power per beam [MW]		30		
Half crossing angle at IP [mrad]		16.5		
Bending radius [km]		10.7		
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
Bunch population [10^10]	20	14	13.5	14
Beam current [mA]	3.3	16.7	84.1	803.5
Momentum compaction [10^-5]	0.71	0.71	1.43	1.43
Beta functions at IP (bx/by) [m/mm]	1.04/2.7	0.33/1	0.21/1	0.13/0.9
Emittance (ex/ey) [nm/pm]	1.4/4.7	0.64/1.3	0.87/1.7	[illegible]27/1.4
Beam size at IP (sigx/sigy) [um/nm]	39/113	15/36	[illegible]	[illegible]/35
Bunch length (SR/total) [mm]	2.2/2.9	2.3/[illegible]	[illegible]	2.5/8.7
Energy spread (SR/total) [%]	0.15/0.20	[illegible]	0.07/0.14	0.04/0.13
Energy acceptance (DA/RF) [%]	2.3/[illegible]	[illegible]/2.2	1.2/2.5	1.3/1.7
Beam-beam parameters (ksix/ksiy)	0.071/[illegible]	0.015/0.11	0.012/0.113	0.004/0.127
RF voltage [GV]	10	2.2	0.7	0.12
RF frequency [MHz]	650	650	650	650
HOM power per cavity (5/2/1cell)[kw]	0.4/0.2/0.1	1/0.4/0.2	-/1.8/0.9	-/-/5.8
Qx/Qy/Qs	0.12/0.22/0.078	0.12/0.22/0.049	0.12/0.22/	0.12/0.22/
Beam lifetime (bb/bs)[min]	81/23	39/18	60/717	80/182202
Beam lifetime [min]	18	12.3	55	80
Hour glass Factor	0.89	0.9	0.9	0.97
Luminosity per IP[1e34/cm^2/s]	0.5	5.0	16	115
		67%⇑		259%⇑

Inputs – Detector Designs

Particle Flow Approach
(ILD-like)

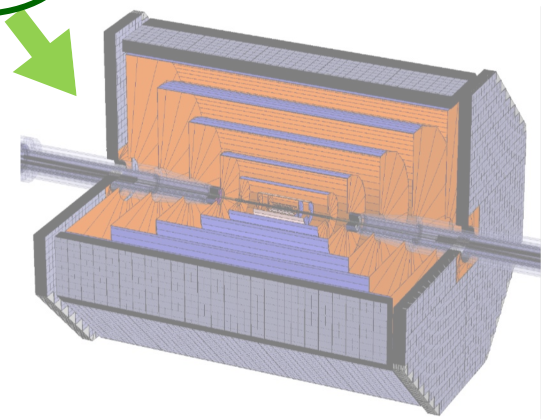


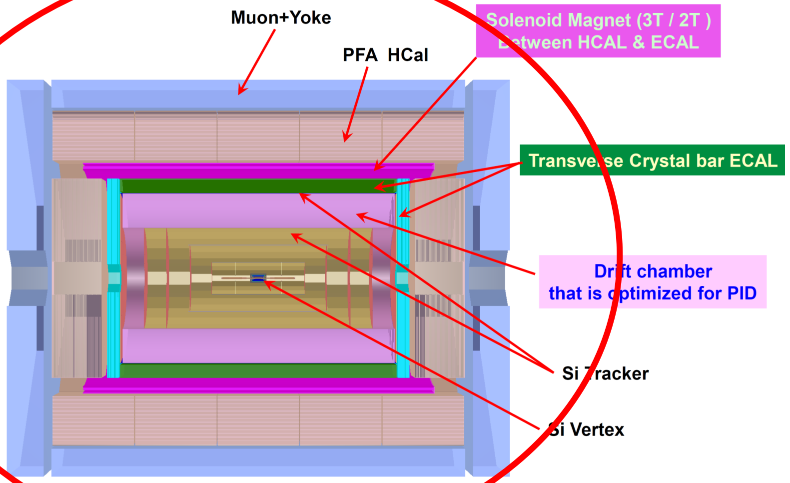


IDEA concept
(also proposed for FCC-ee)

Si Vertex, Si + TPC, PFA ECal &HCal,

Full Silicon Tracker (FST) concept

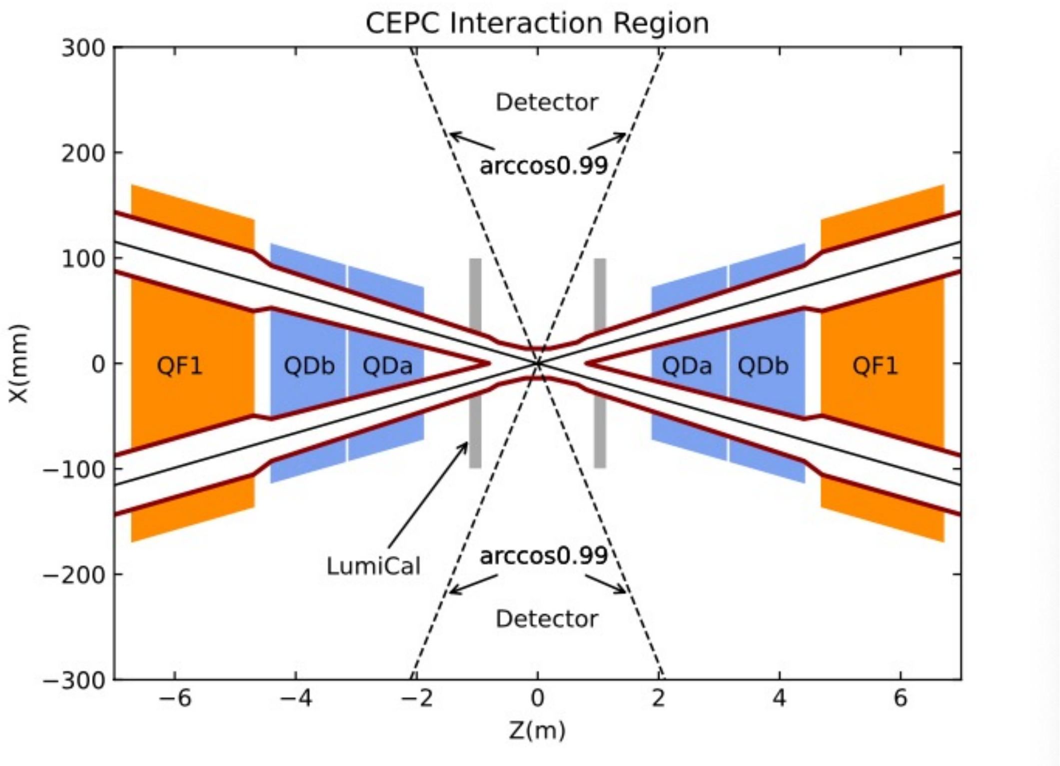




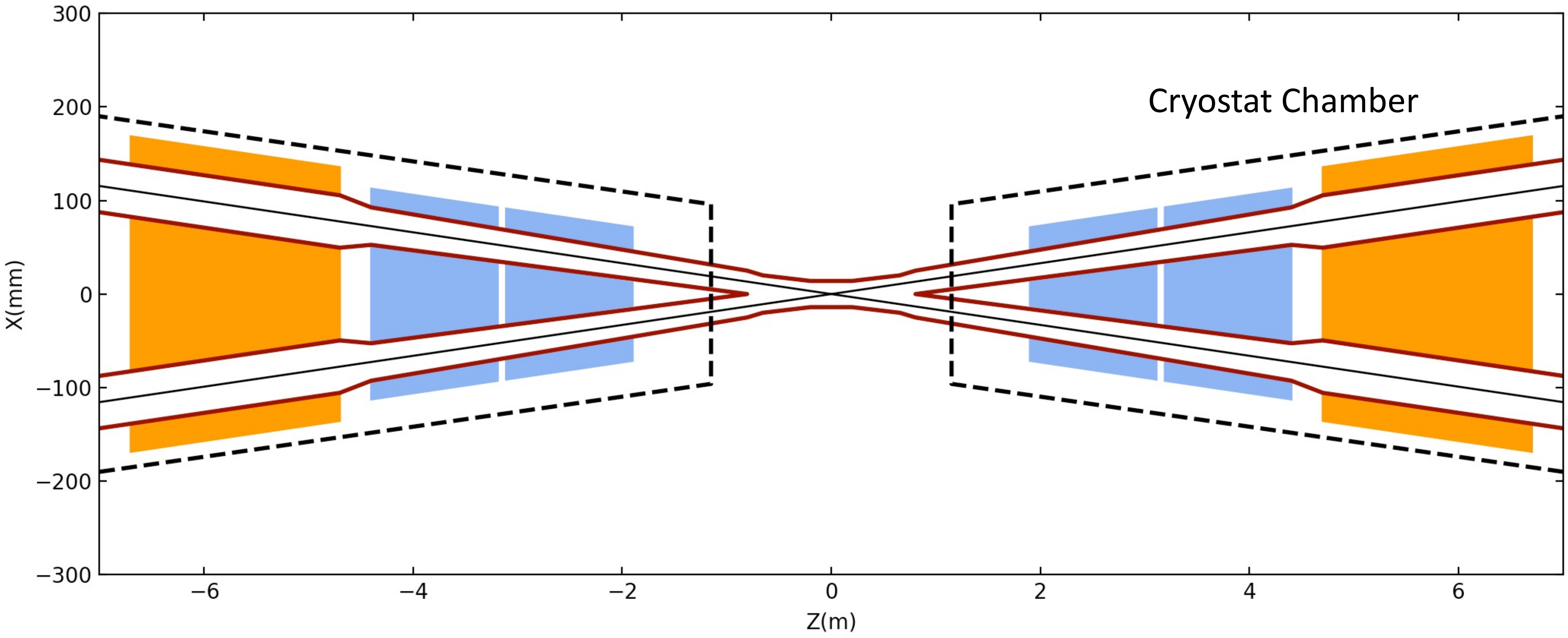
4^{th} Detector concept

Physics Design

- Interaction Region Layout/Parameters
  - L* = 1.9m / Detector Acceptance = 0.99
- Estimation of the Radiation Level/Heat Deposition

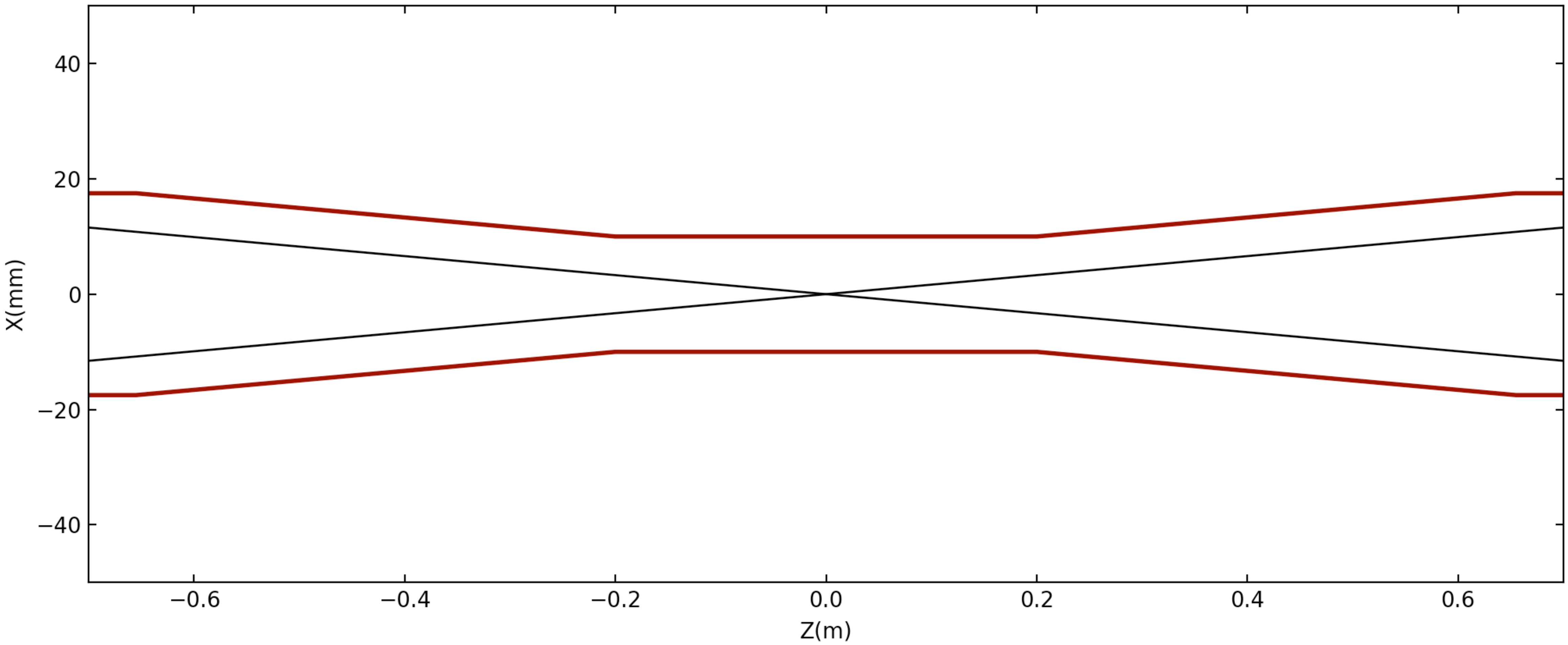


New Beampipe Design – Whole IR



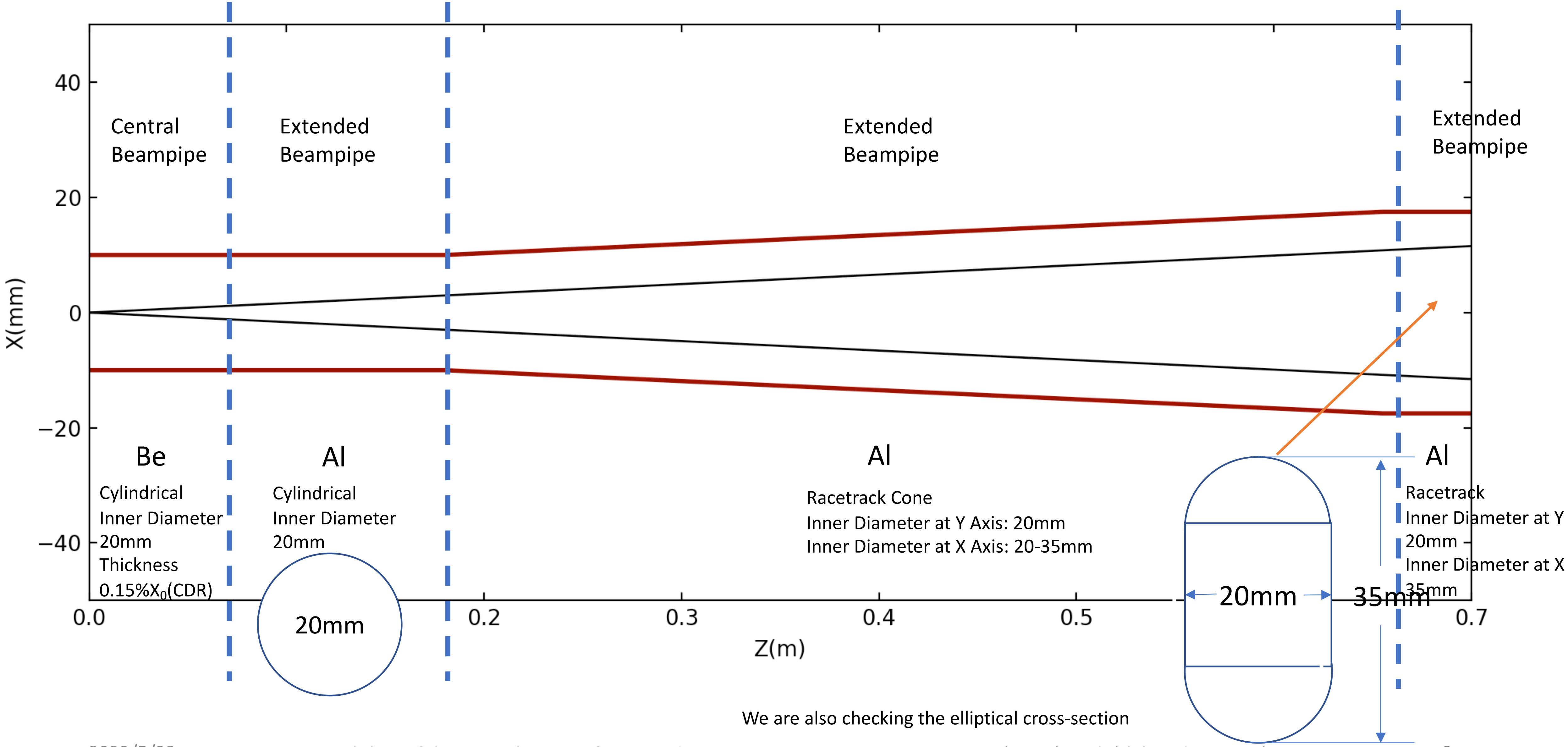
The length of Interaction Region is -7m~7m on TDR Phase

New Beampipe Design – Detector Beampipe



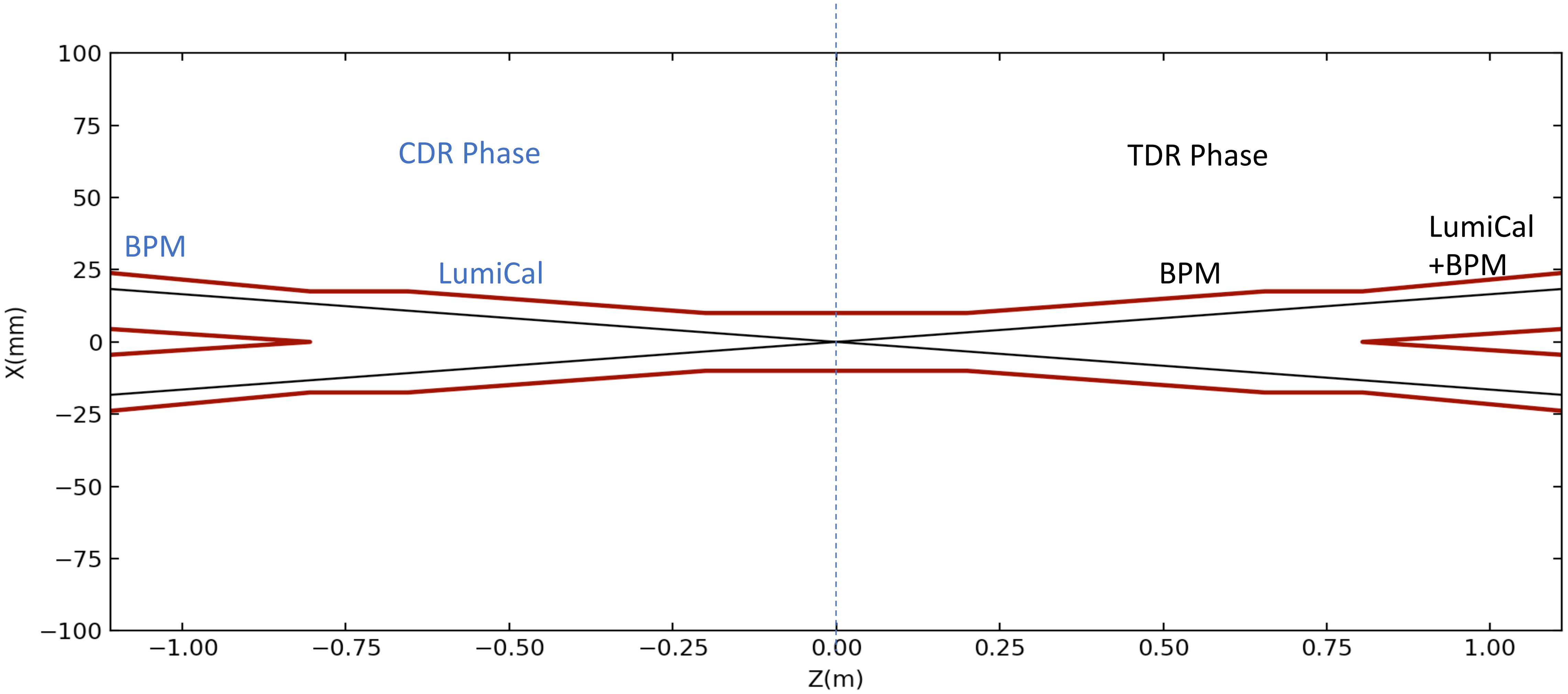
Symmetry Design with increasing aperture

New Beampipe Design – Half Detector pipe



We are also checking the elliptical cross-section

New Beampipe Design – Cryo to Cryo

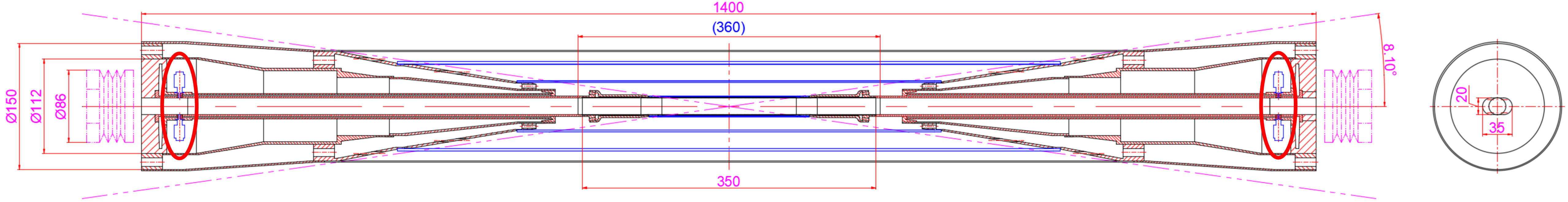


The range between 2 cryostat chambers would be -1.11m~1.11m

Interfaces between pipe and BPM

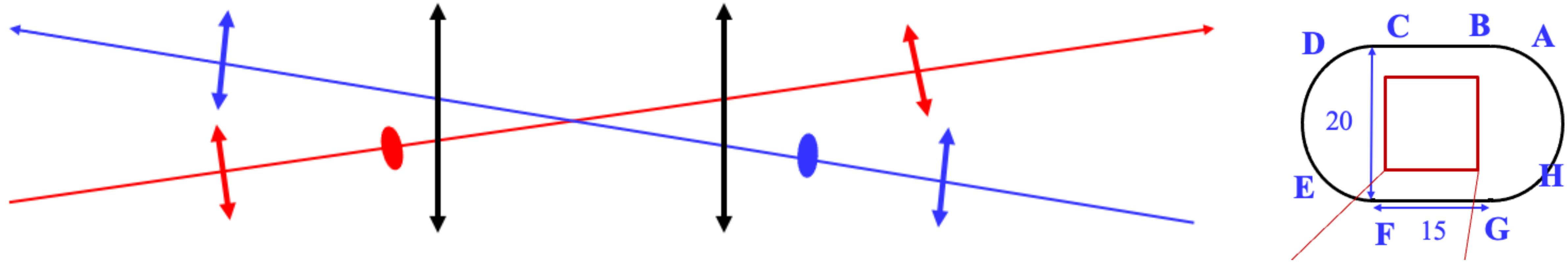
- We plan to have at least a pair of double electrodes BPM

Q. Ji



- But above setting could only measure the timing/position at Y axis
- If we want to have more, we may need octo-electrodes BPM, and the position optimization was required.

J. He



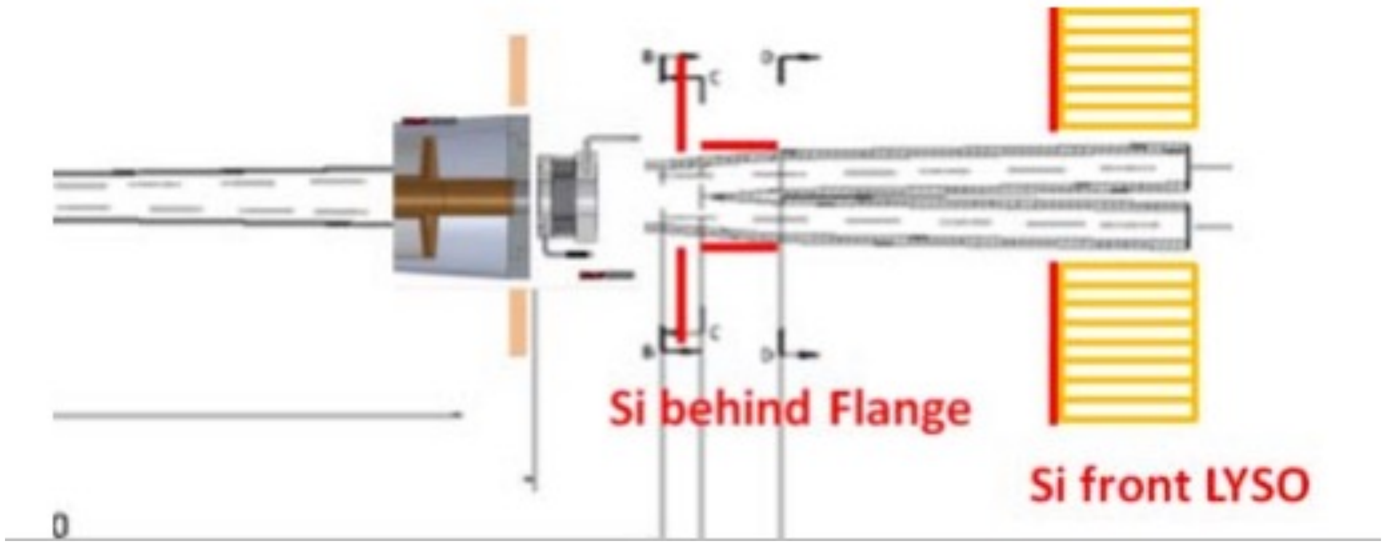
Interfaces between pipe and LumiCal

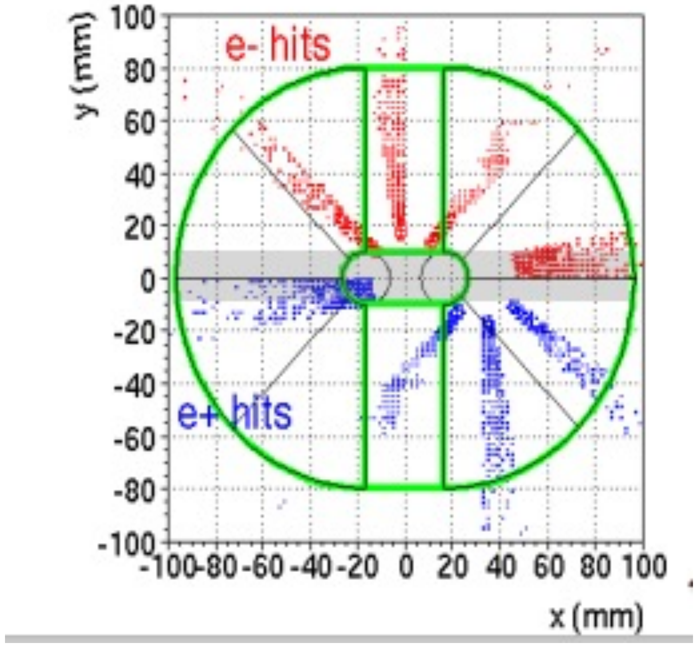
With LumiCal:

Please refer to Ivan's talk later today, and Suen's talk tomorrow

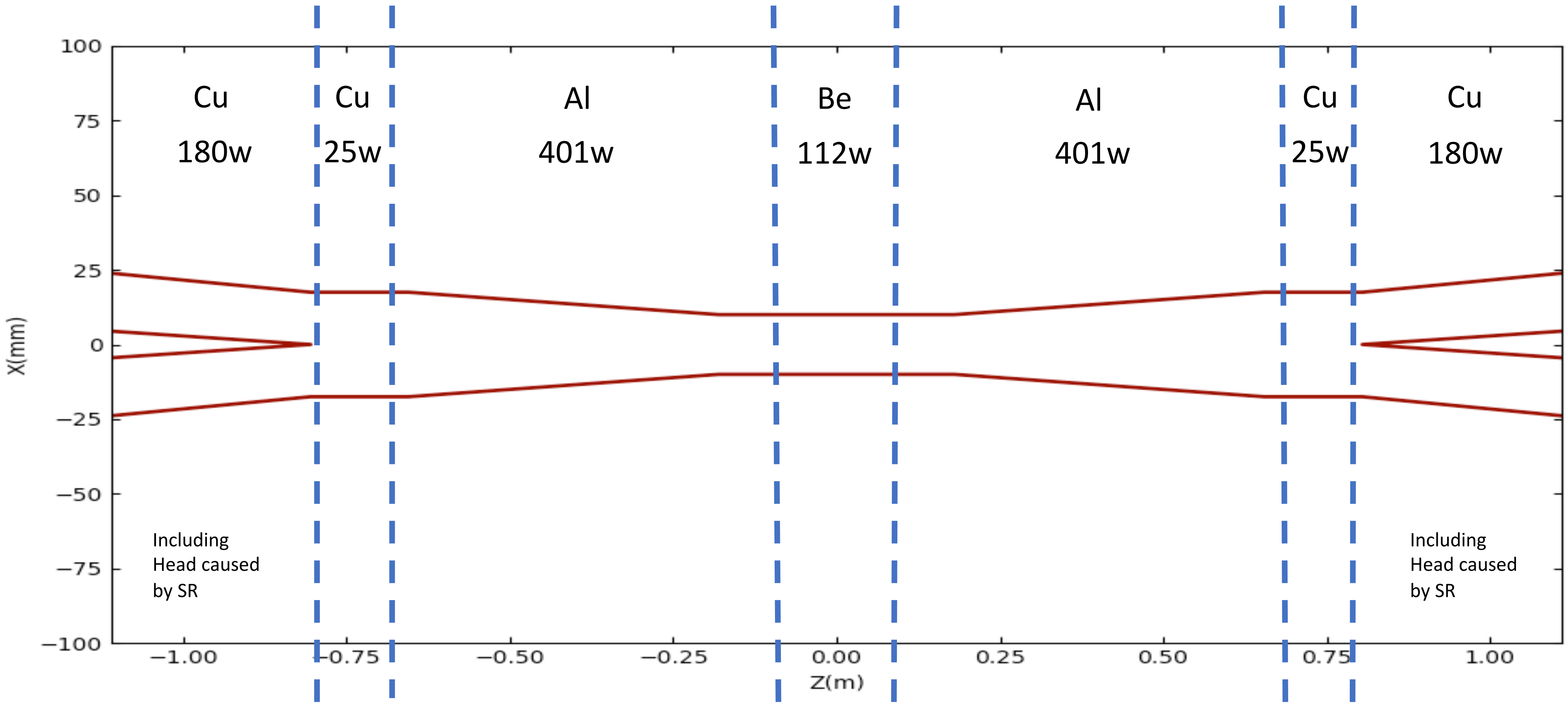
- Will not be putted at detector beampipe region.
  - Therefore, the material of extended beam pipe could be changed.
- The material and thickness(material budget) of the flange&bellow needs to be calculated.

S. Hou





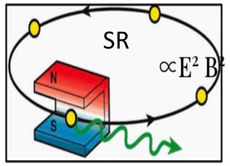
Heat Deposition



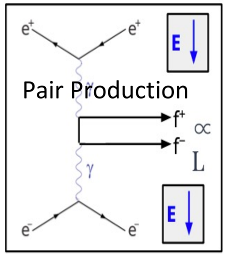
We are considering to change the material beyond bellows to Al due to demands of LumiCal, it wouldn’t affect heat deposition to much

Background Estimation

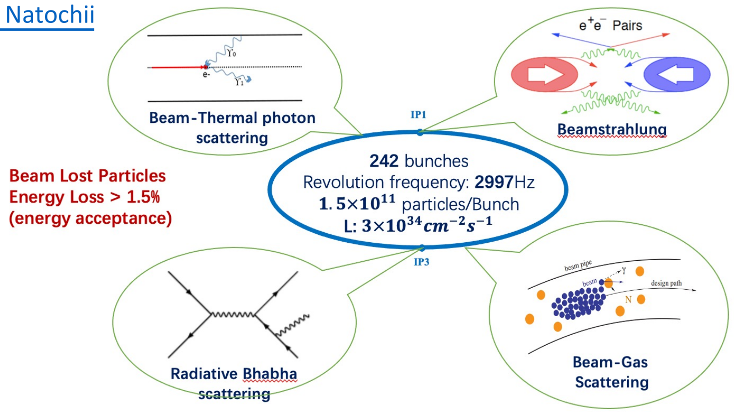
- Simulate each background separately
- Whole-Ring generation for single beam BGs
- Multi-turn tracking(50 turns)
  - Using built-in LOSSMAP with one step ahead output
  - SR emitting/RF on
  - Radtaper on
  - No detector solenoid
- Errors implemented
  - High order error for magnets
  - Beam-beam effect
- 2 IR considered
- We are also updating our toolkit to latest version.
- Plan to study the photon bgs generated during BGB/BTH/RBB…



A. Natochii

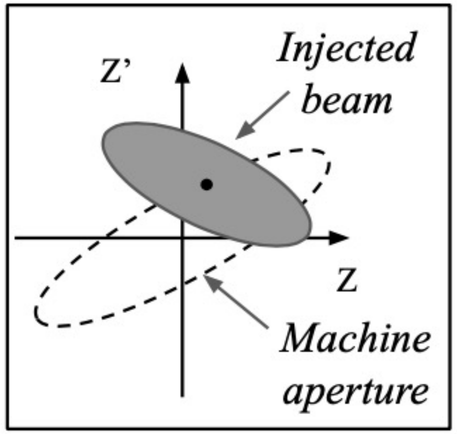


Photon BG



Beam Loss BG

A. Natochii



Injection BG

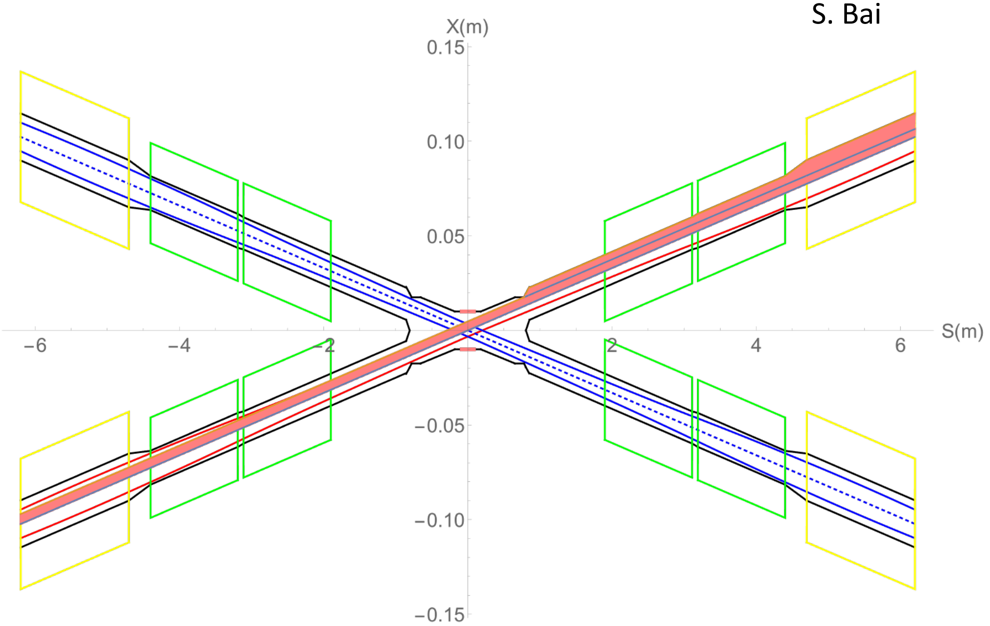
Background	Generation	Tracking	Detector Simu.
Synchrotron Radiation	BDSim	BDSim/Geant4	Mokka/CEPCSW
Beamstrahlung/Pair Production	Guinea-Pig++	SAD	
Beam-Thermal Photon	PyBTH[Ref]		
Beam-Gas Bremsstrahlung	PyBGB[Ref]		
Beam-Gas Coulomb	BGC in SAD		
Radiative Bhabha	BBBREM		

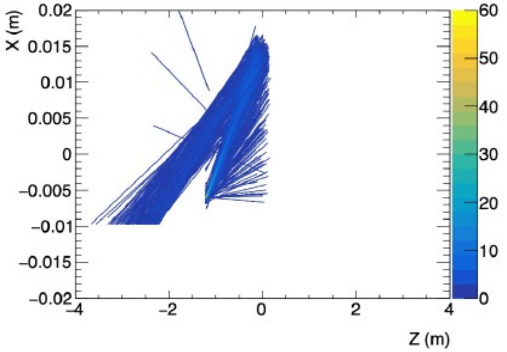
SR BG & Mitigation

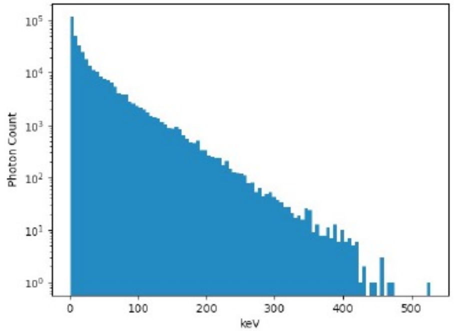
Please refer to Yue's talk tomorrow.

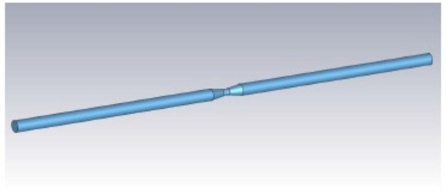
- The SR must be dealt with high priority when designing the circular machine. At CEPC, there would be no SR photons hitting the central beam pipe directly in normal conditions
- However, some secondaries generated within QD would hit the detector beampipe, even the beryllium part. Therefore, the mitigation methods must be studied. We compared several methods based on CDR, and we believe the results can also be used on TDR with optimization.

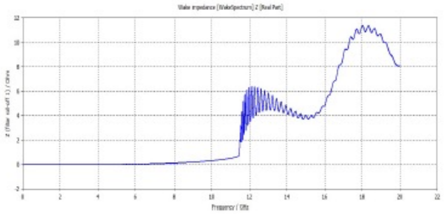
S. Bai









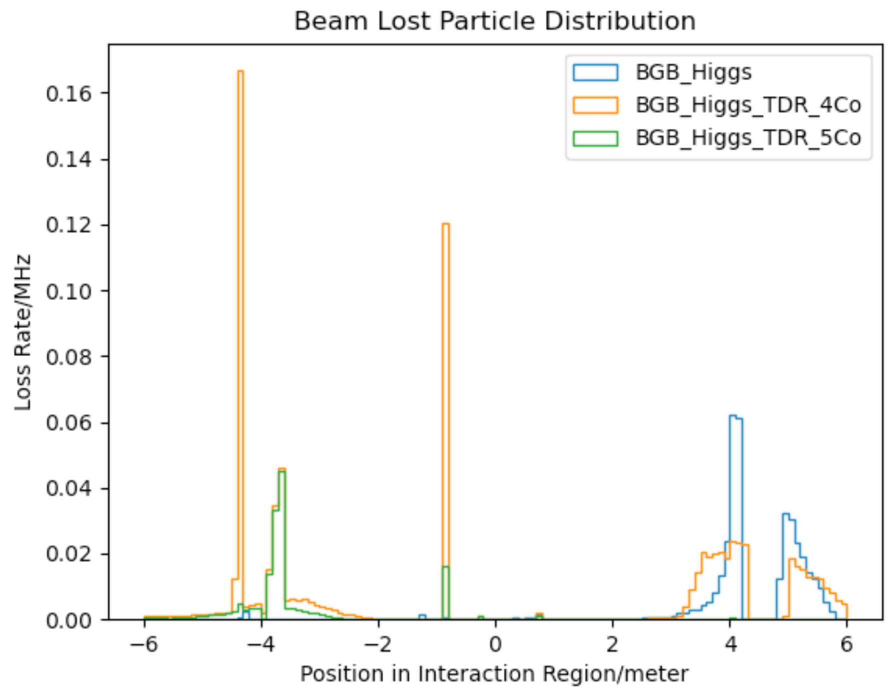


Mitigation of the BG - Collimator

- Beam stay clear region: 18 σ_x+3mm, 22 σ_y+3mm
- Impedance requirement: slope angle of collimator < 0.1
- 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

S. Bai

name	Position	Distance to IP/m	Beta function/m	Horizontal Dispersion /m	Phase	BSC/2/m	Range of half width allowed/m m
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	DMBV01IR U0	56.3	196.59	0	362.86	0.01178	2.9~11.78



TDR Estimation – with safety factor of 10

- For fast estimation, we try to perform some scaling based on CDR results according to Luminosity.
- We also performing the full-TDR simulation. But it takes time.
- We plan to have double check on detector simulation(Mokka/CEPCSW/FLUKA)
  - We learn that the background impact on LumiCal must be studied.

Scaling Results on 1st layer of vertex detector

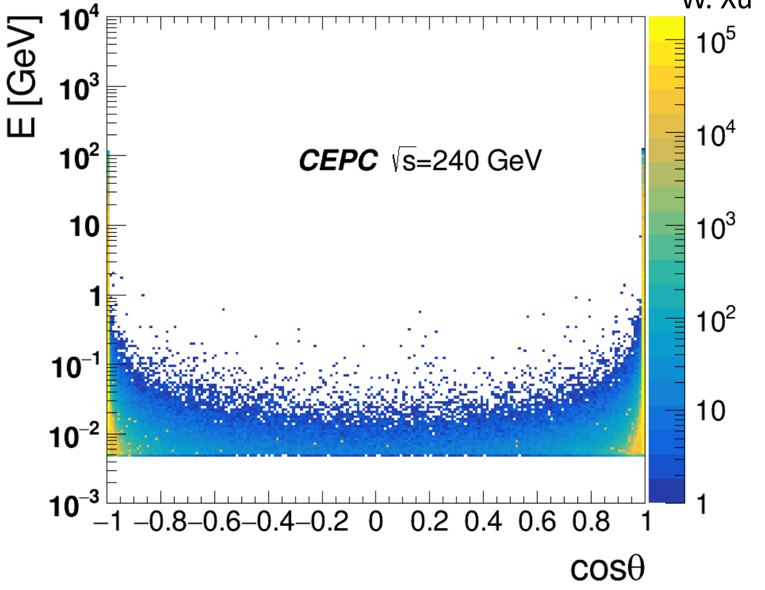
W. Xu

	CDR	TDR(30MW)	TDR(50MW)
Higgs (3T)	2.93	5.00	8.00
Z (2T)	32.1	115.0	184.0

	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

TDR Pair-Production Distribution

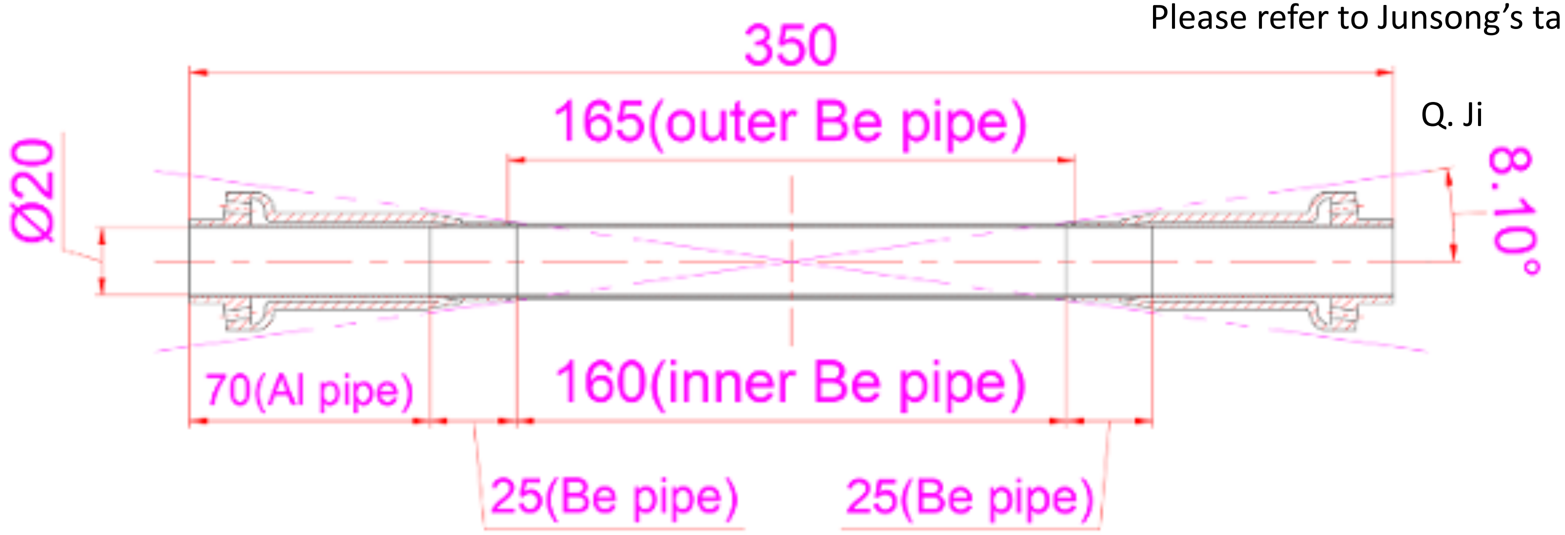
W. Xu



Mechanical Design of the detector beam pipe

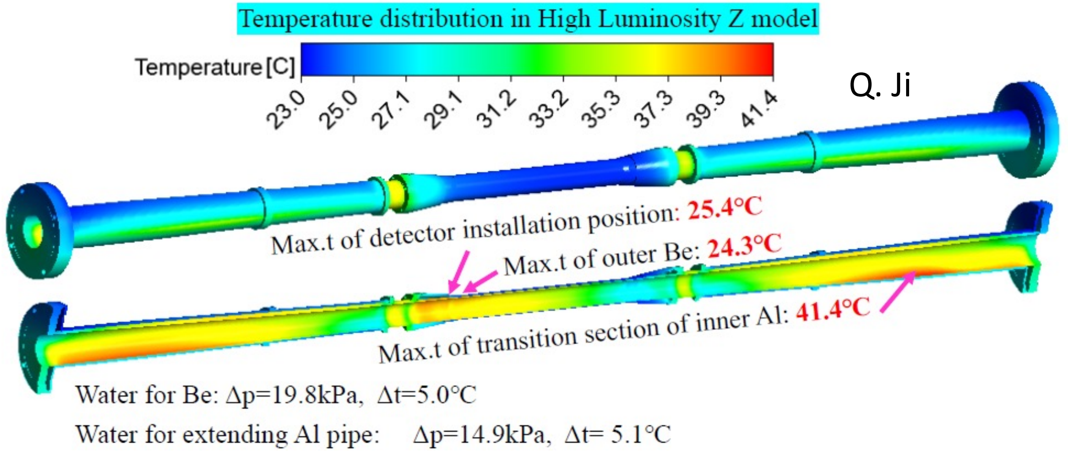
Please refer to Junsong's talk tomorrow

Outer Be Layer: 0.15mm
Gap: 0.35mm
Inner Be Layer: 0.2mm
Thickness: ~0.2%X_0



- Coolant might be paraffin or water.
  - If water was chosen, then the corrosion on Be must be studied.
- At CDR phase, the thermal analysis with 5kw heat deposition rate and 28mm inner diameter has been studied. The latest case is under analysis.

CDR High-Z results(5kw in total)



Summary & Outlook

- We are moving our design to TDR phase.
  - Layout & Physics design has been updated.
  - The heat deposition calculation was done.
  - The estimation of radiation level caused by BG is under simulation.
  - The mechanical design is updating, including the thermal analysis based on the deposited heat.
  - We plan to have a preliminary whole TDR MDI design before next CEPC workshop.
- The optimization and validation of current design is always needed.
  - The BESIII backgrounds experiment was done last summer. We hope we could have another run this summer.
  - Validate our BG simulation codes using BEPCII and SuperKEKB.

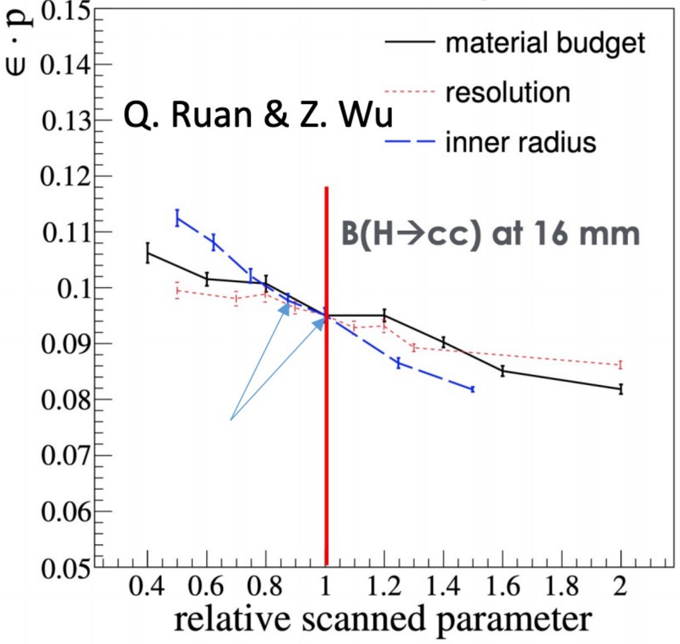
Thank You

Backup

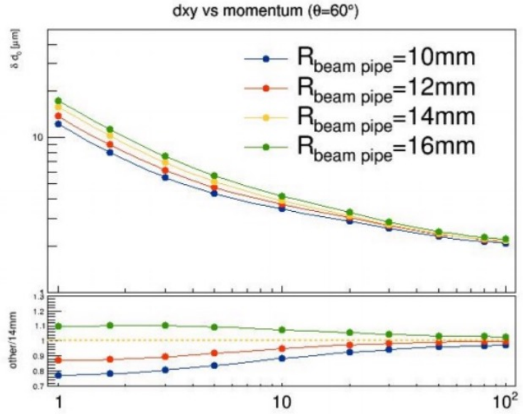
Physics Gains for 20mm Be

- First estimates made with fast simulation and scaling

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



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

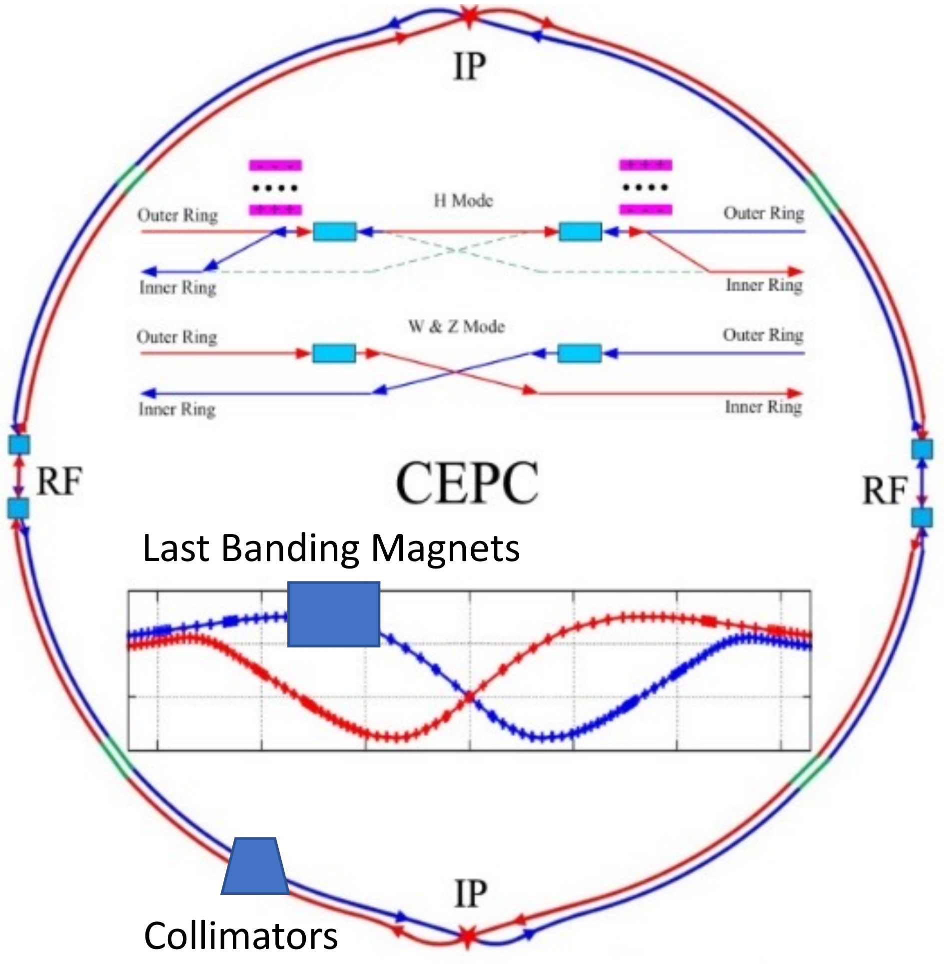


H. Zeng

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

G. Li

Map of the MDI Study



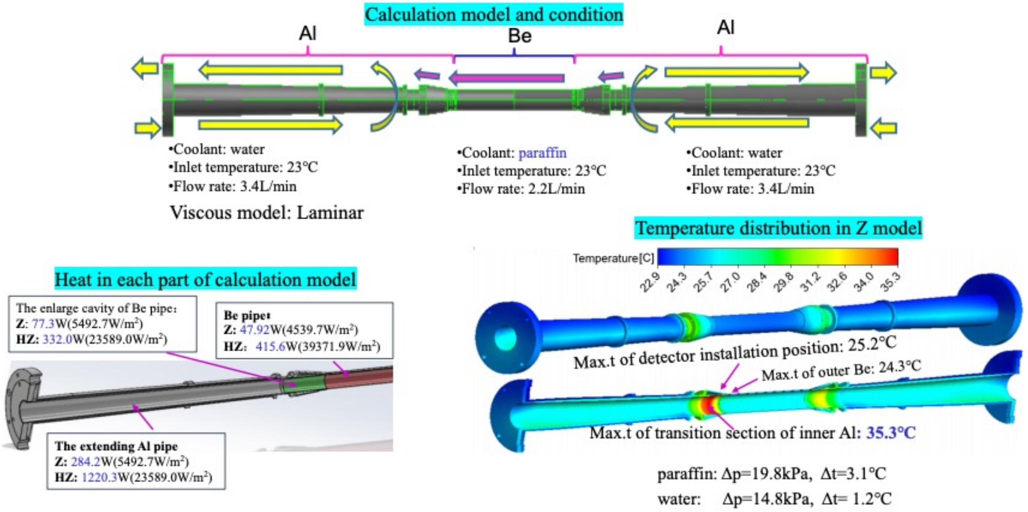
Accelerator

- IP Feedback
- BG Simulation
- LumiCal
- 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

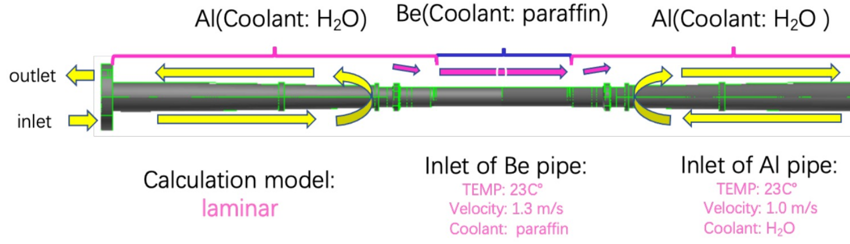
- Central Beam Pipe
- Vertex Detector
- LumiCal
- Silicon Tracker
- TPC
- Hcal
- Ecal
- Solenoid
- Yoke
- Muon Detector
- Hall
- BG Simulation&Shielding
- Software Geometry
- Alignment&Assembly
- Electronics
- Cryogenic
- Radiation Protection
- Booster

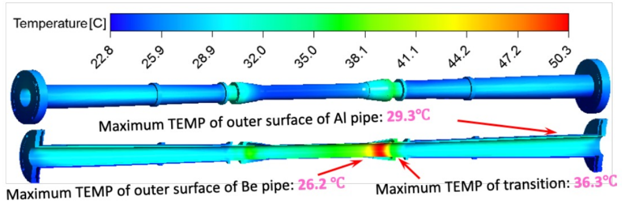
Thermal Analysis - CDR



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:
Be pipe : 3.2 ℃
Transition: 13.3 ℃
Al pipe : 6.3 ℃

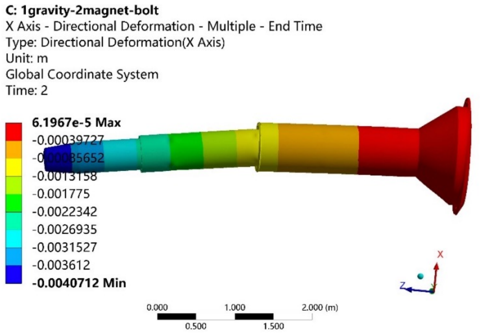
Pressure drop:
Be pipe : 19.8 kPa
Al pipe : 19.3 kPa

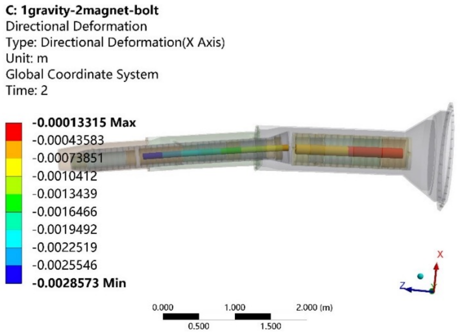
Conclusion:
Temperature rise and pressure drop within safe range

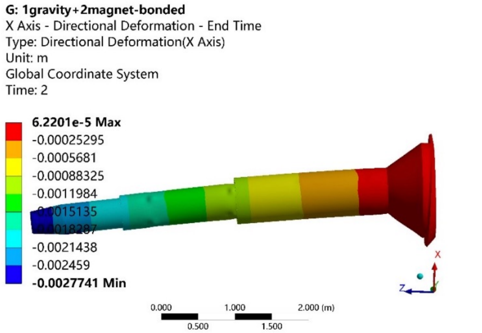
Mechanical Calculation and Optimization-CDR

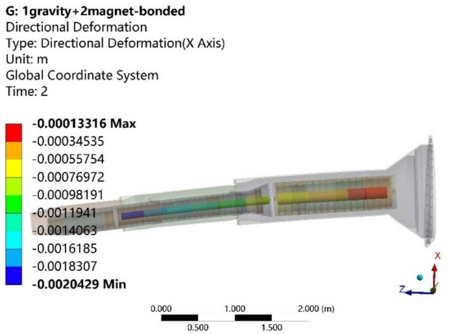
Refer to [Haijing's Talk]

Deformation Calculation

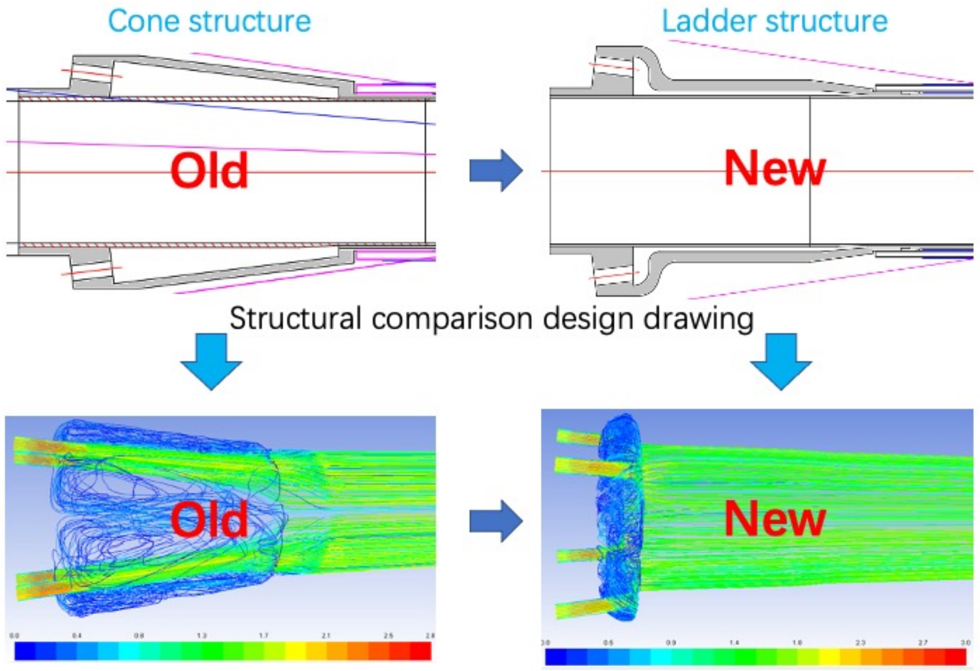








Detailed Beampipe Design



Streamline comparison chart

Updates on BG Simulation

- The detector simulation(with a safety factor of 10 for TID/NIEL):
  - Detector Impacts, Vertex : CDR→TDR(Scale)

Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($\boldsymbol{cm^{-2} \cdot BX^{-1}}$)	2.3	2.3	2.3	0.63	0.63	0.63
TID($\boldsymbol{krad \cdot yr^{-1}}$)	930	1490	2540	10.5	3150	5360
NIEL($\boldsymbol{n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}}$)	2.2	3,5	6.0	23.6	70.8	120.4

  - Detector Impacts, TPC : CDR→TDR(Scale)

Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($\boldsymbol{cm^{-2} \cdot BX^{-1}}$)	2.59e-2	2.59e-2	2.59e-2	6.365e-3	6.365e-3	6.365e-3
TID($\boldsymbol{krad \cdot yr^{-1}}$)	4.385	7.483	11.973	67.53	241.93	387.09
NIEL($\boldsymbol{n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}}$)	0.4519	0.7712	1.234	7.415	26.565	42.503

Updates on BG Simulation

- The detector simulation(with a safety factor of 10 for TID/NIEL):
  - Detector Impacts, Ecal Barrel : CDR→TDR(Scale)

Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($cm^{-2} \cdot BX^{-1}$)	1.162e-3	1.162e-3	1.162e-3	2.714e-4	2.714e-4	2.714e-4
TID($krad \cdot yr^{-1}$)	0.319	0.544	0.871	5.505	19.722	31.555
NIEL($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)	0.1285	0.2193	0.3509	1.396	5.001	8.002

  - Detector Impacts, Ecal Endcup: CDR→TDR(Scale)

Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($cm^{-2} \cdot BX^{-1}$)	1.356e-3	1.356e-3	1.356e-3	2.335e-4	2.335e-4	2.335e-4
TID($krad \cdot yr^{-1}$)	0.2841	0.4848	0.7757	2.473	8.860	14.175
NIEL($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)	0.1248	0.2130	0.3408	1.069	3.830	6.128

Updates on BG Simulation

- The detector simulation(with a safety factor of 10 for TID/NIEL):
  - Detector Impacts, HCal Barrel : CDR→TDR(Scale)

Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($\boldsymbol{cm^{-2}\cdot BX^{-1}}$)	2.778e-5	2.778e-5	2.778e-5	1.1e-5	1.1e-5	1.1e-5
TID($\boldsymbol{krad\cdot yr^{-1}}$)	7.603e-3	12.974e-3	20.76e-3	0.2529	0.906	1.450
NIEL($\boldsymbol{n_{eq}\times 10^{12}\cdot cm^{-2}\cdot yr^{-1}}$)	0.0116	0.198	0.317	0.1627	0.5829	0.9326

  - Detector Impacts, HCal Endcup: CDR→TDR(Scale)

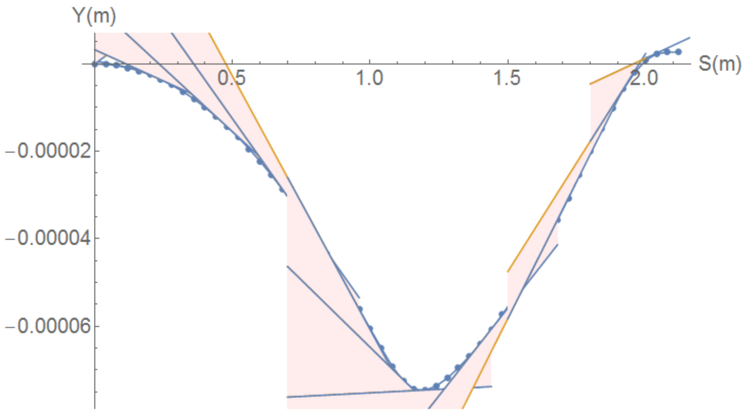
Wei Xu

	Higgs			Z		
	CDR	TDR-30	TDR-50	CDR	TDR-30	TDR-50
Hit Density($\boldsymbol{cm^{-2}\cdot BX^{-1}}$)	1.321e-3	1.321e-3	1.321e-3	2.732e-4	2.732e-4	2.732e-4
TID($\boldsymbol{krad\cdot yr^{-1}}$)	0.284	0.485	0.775	4.589	16.44	26.31
NIEL($\boldsymbol{n_{eq}\times 10^{12}\cdot cm^{-2}\cdot yr^{-1}}$)	0.159	0.271	0.434	1.108	3.97	6.351

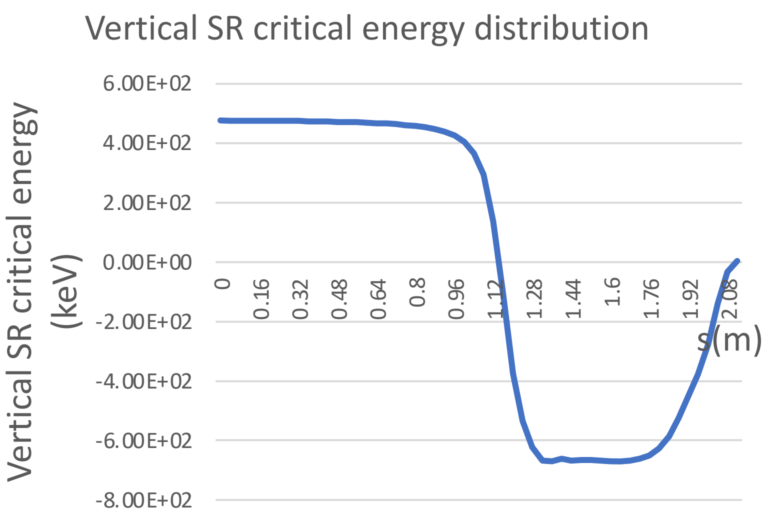
SR from solenoid combined field

S. Bai

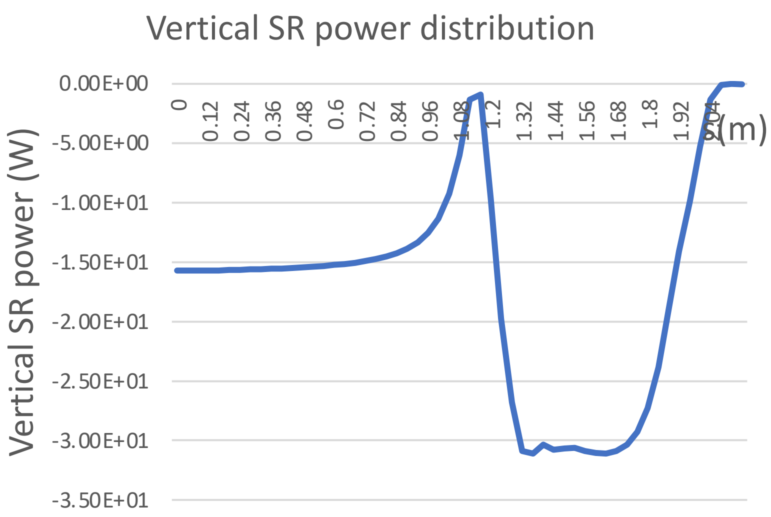
- Horizontal trajectory will couple to the vertical
- Due to the sol+anti-sol field strength quite high, maximum~4.24T, transverse magnetic field component is quite high.
- SR from vertical trajectory in sol+anti-sol combined field should be taken into account.



- 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