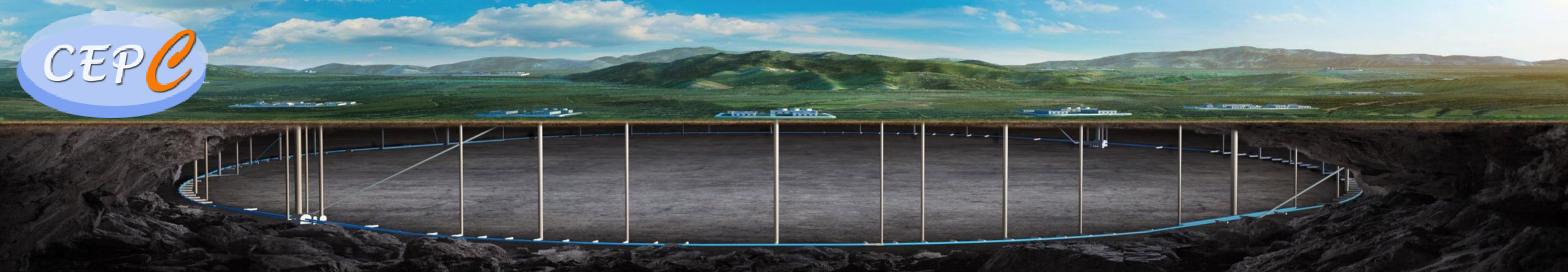

CEPC Beam Backgrounds Status & MDI Updates

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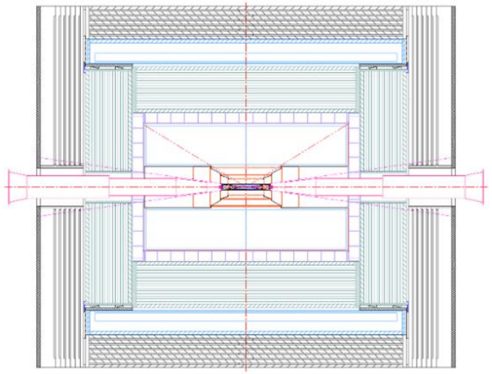
Content

- Introduction
- Sources, tools, mitigation methods
- Impacts Estimation
- Shielding of the BIB
- Summary & Outlook

Introduction

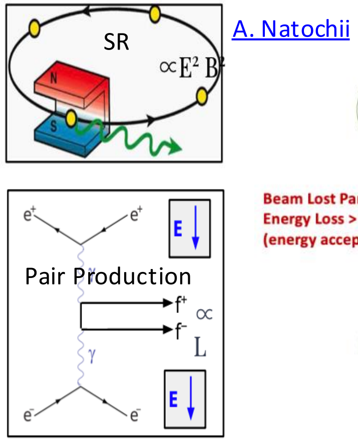
- Reasonable Estimation of Beam-induced background levels
  - Based on the 50-MW design of CEPC Accelerator TDR
  - Keep updating with the Ref-TDR detector
  - Higgs, Low-Lumi-Z, High-Lum-Z(2T)
- Estimation of the Noise on Detector due to Backgrounds, Normal Operation
  - Hit Rate/Occupancy
- Estimation of the Radiation Environment: contributions from Backgrounds in normal operation(the failure case, contributions from the signal will be considered later)
  - Radiation Damage to the Material(Detector, Accelerator, Electronics, etc…)
  - Radiation Damage to the personnel and the environment
  - Absorbed Dose, 1 MeV Si-eq fluence, Hadron fluence…
- Mitigation Methods

	Higgs (3T)	Low-Lumi Z (3T)	High-Lumi Z (2T)	W (3T)	$t\bar{t}$ (3T)
Number of IPs	2				
Circumference (km)	99.955				
Half crossing angle at IP (mrad)	16.5				
Bending radius (km)	10.7				
SR power per beam (MW)	50				
Energy (GeV)	120	45.5	45.5	80	180
Energy loss per turn (GeV)	1.8	0.037	0.037	0.357	9.1
Damping time $\tau_x/\tau_y/\tau_z$ (ms)	44.6/44.6/22.3	816/816/408	816/816/408	150/150/75	13.2/13.2/6.6
Piwinski angle	4.88	24	29.52	5.98	1.23
Bunch number	446	3978	13104	2162	58
Bunch spacing (ns)	277.0	69.2	23.1	138.5	2585.0
[× 23.08 ns]	12	3	1	6	112
Train gap [%]	63	9	9	10	55
Bunch population (10^{11})	1.3	1.7	2.14	1.35	2.0
Beam current (mA)	27.8	325.0	1340.9	140.2	5.5
Phase advance of arc FODO (°)	90	**60**	60	60	90
Momentum compaction (10^{-5})	0.71	1.43	1.43	1.43	0.71
Beta functions at IP β_x^*/β_y^* (m/mm)	0.3/1	0.13/1.0	0.13/0.9	0.21/1	1.04/2.7
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/5.1	0.27/1.4	0.87/1.7	1.4/4.7
Betatron tune ν_x/ν_y	445/445	317/317	317/317	317/317	445/445
Beam size at IP σ_x/σ_y (um/nm)	14/36	6/72	6/35	13/42	39/113
Bunch length (natural/total) (mm)	2.3/4.1	2.5/8.8	2.7/10.6	2.5/4.9	2.2/2.9
Energy spread (natural/total) (%)	0.10/0.17	0.04/0.13	0.04/0.15	0.07/0.14	0.15/0.20
Energy acceptance (DA/RF) (%)	1.6/2.2	1.0/1.7	1.0/1.5	1.05/2.5	2.0/2.6
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.0053/0.082	0.0045/0.13	0.012/0.113	0.071/0.1
RF voltage (GV)	2.2	0.12	0.1	0.7	10
RF frequency (MHz)	650				
Harmonic number	216720				
Longitudinal tune ν_s	0.049	0.035	0.032	0.062	0.078
Beam lifetime (Bhabha/beamstrahlung) (min)	40/40	150/180	90/930	60/195	81/23
Beam lifetime requirement (min)	20	68	81	25	18
Luminosity per IP (10^{34} cm^{-2} s^{-1})	8.3	26	192	26.7	0.8

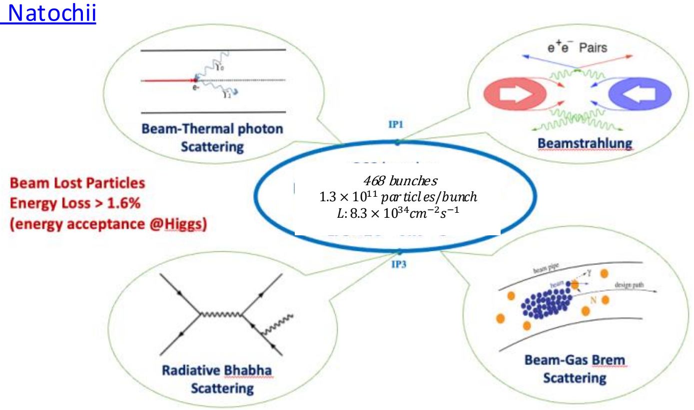


Sources and Simulation Tools

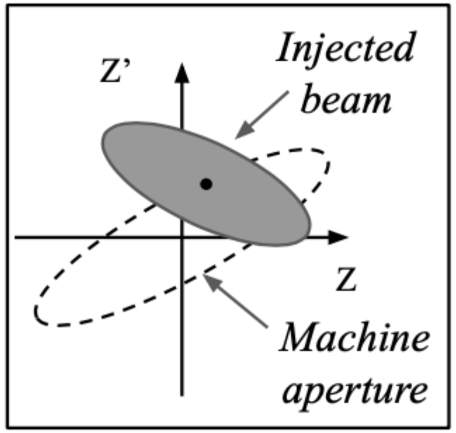
- **Single Beam**
  - Touschek Scattering
  - Beam Gas Scattering(Elastic/inelastic)
  - Beam Thermal Photon Scattering
  - Synchrotron Radiation
- **Luminosity Related**
  - Beamstrahlung
  - Radiative Bhabha Scattering
- **Injection(Will be considered future)**



Photon BG



Beam Loss BG



Injection BG

Background	Generation	Tracking	Detector Simu.
Synchrotron Radiation	BDSim/Geant4	BDSim/Geant4	CEPCSW/FLUKA
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		
Touschek	TSC in SAD		

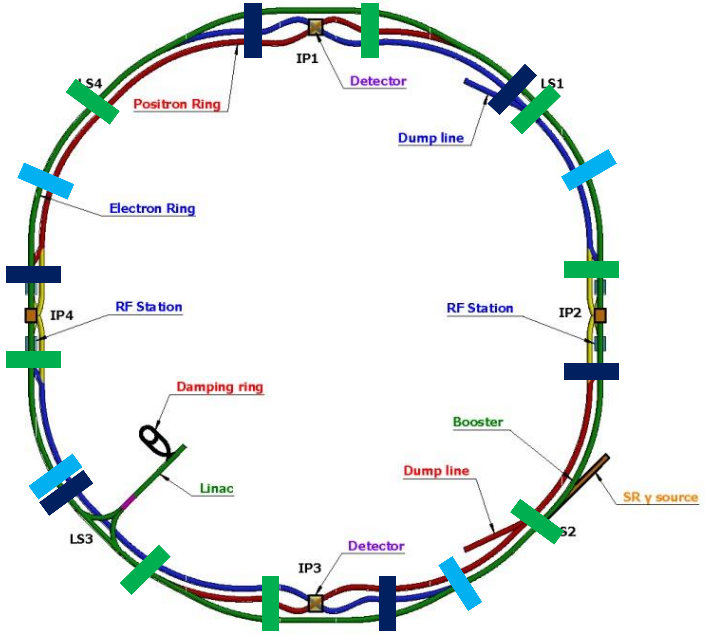
Mitigation of the BIBs

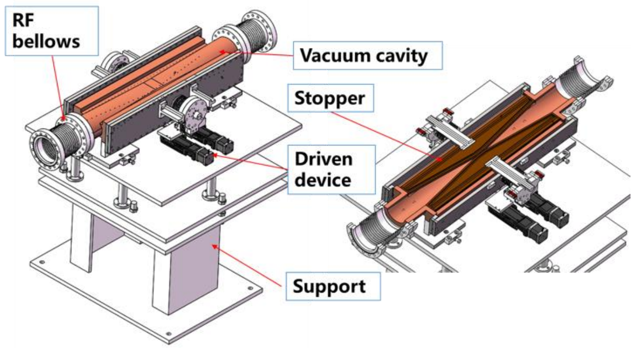
- The sources of the BIBs has two groups:
  - From IP, luminosity related(pair-production, radiative Bhabha)
  - From anywhere around the ring, less in IP(single beam losses and SR)
- Previously, we have several methods of shielding(or mitigation)
  - Using collimators to block single beam loss outside of the IR
  - Using mask to block SR outside of the Be beam pipe
  - Using heavy metal(like W) somewhere in the IR(like outside the cryomodule)
  - Using paraffine at both ends of the yoke(together with concrete wall maybe) to block the upstream single loss entering the IR

Collimators

- Collimators were implemented to reduce IR loss caused by single beam.
  – 18 sets of collimators were implemented for MDI purpose with updated position
  – ~20 sets of collimators were installed for passive machine protection and will also contribute to mitigating beam background.
  – With the implementation of collimators, multi-turn beamstrahlung and radiative Bhabha loss particles have been effectively shielded outside the interaction region.

Xiaohao Cui, Yuting Wang, Sha Bai





Haijing Wang

for H betatron collimator

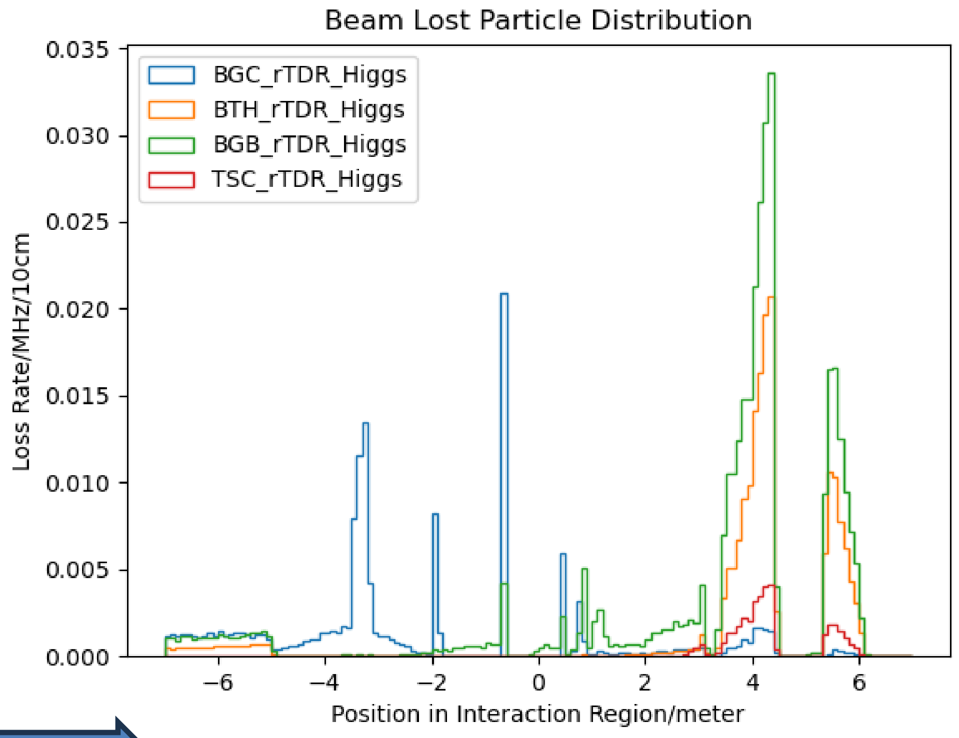
for momentum collimator

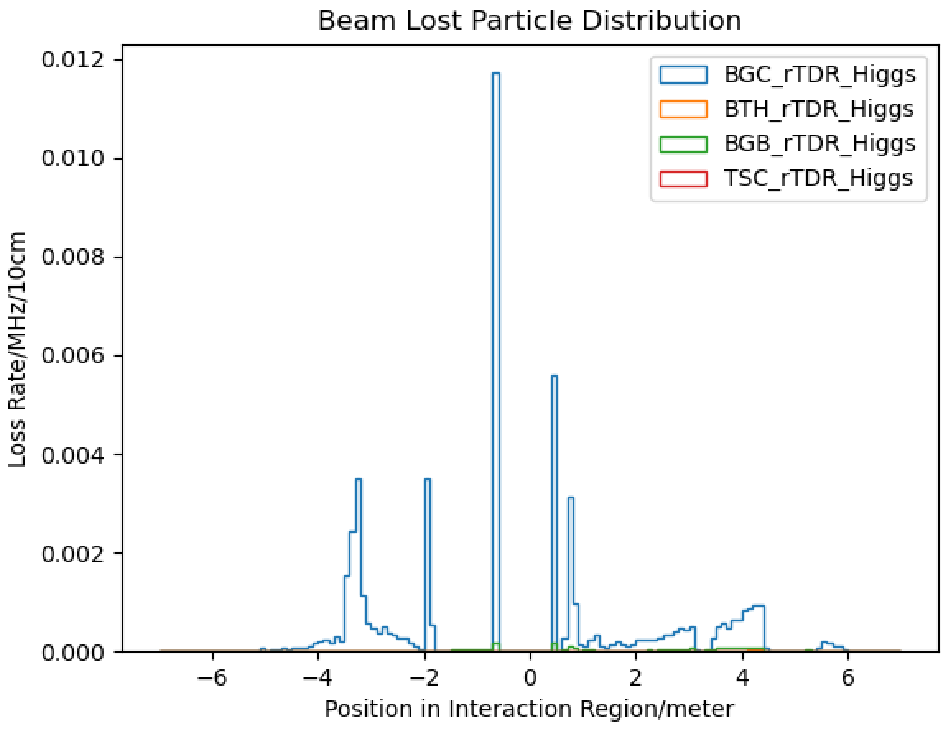
for vertical collimator

Loss Map at the IR @ Higgs

- Single Beam only
- Errors implemented
  - High order error for magnets
  - Beam-beam effect

$$Loss\ Rate = \frac{Loss\ Number}{Loss\ Time} = \frac{Bunch\ number * Particles\ per\ Bunch * (1 - e^{-1})}{Beam\ Lifetime}$$





Beam Way

Loss Map at the IR @ Higgs

- Single Beam only
- Errors implemented
  - High order error for magnets
  - Beam-beam effect

$$Loss\ Rate = \frac{Loss\ Number}{Loss\ Time} = \frac{Bunch\ number * Particles\ per\ Bunch * (1 - e^{-1})}{Beam\ Lifetime}$$

	50MW Higgs, 346ns/BX
Pair Production	~1.82GHz in IR
Beam Thermal Photon	~0.30MHz/beam in IR
Beam Gas Bremsstrahlung	~0.04MHz/beam in IR
Beam Gas Coulomb	~0.23MHz/beam in IR
Touschek Scattering	~0.06MHz/beam in IR
SR	~630 PHz/beam generated at last bending magnet

→

	50MW Higgs, 277ns/BX
Pair Production	~1.82 GHz in IR
Beam Thermal Photon	~0.3 kHz/beam in IR
Beam Gas Bremsstrahlung	~4.1 kHz/beam in IR
Beam Gas Coulomb	~87.8 kHz/beam in IR
Touschek Scattering	~0.3 kHz/beam in IR
SR	~630 PHz/beam generated at last bending magnet

SR only contains last bending magnet and the contributions from solenoid.
Quads(especially from beam tail passing quads) will be implemented later.

Comparing with FCC-ee @ Higgs

- At, higgs, pair production dominates@ CEPC.
- FCC-ee also has their higgs study results. The generator is same.
  - At same level

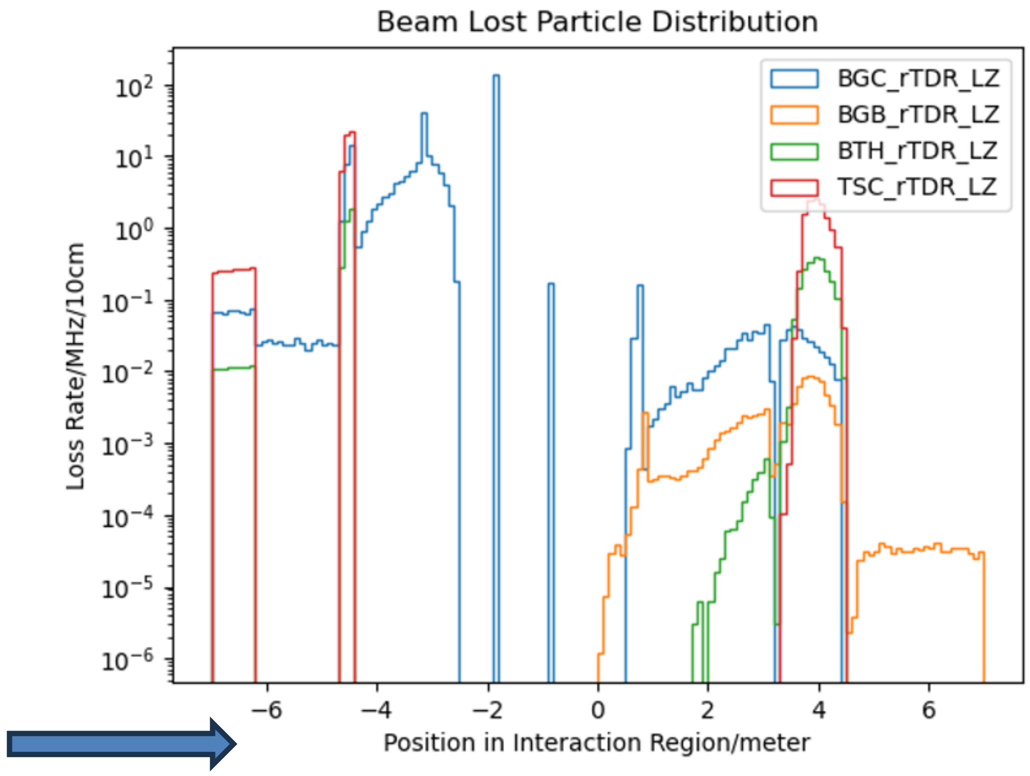
Manuela Boscolo, Andrea Ciarma

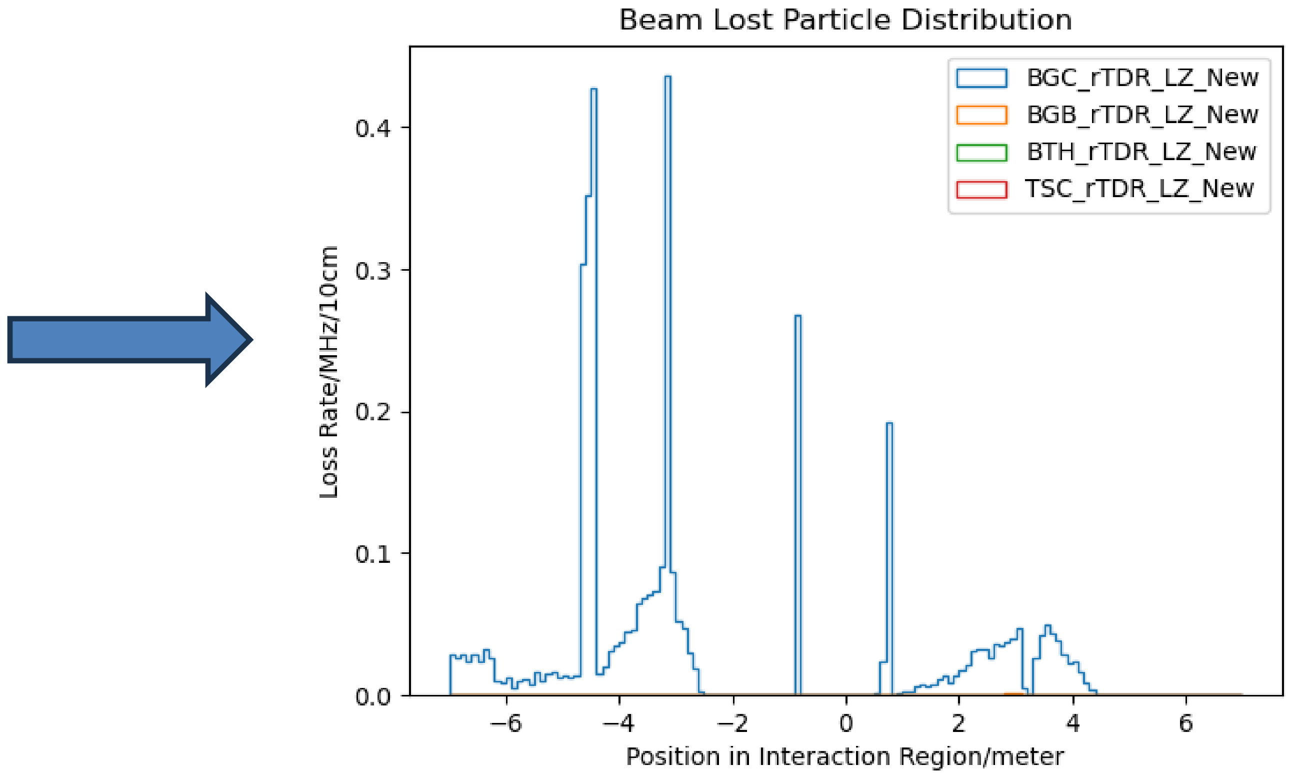
	CEPC	FCC-ee
Pair produced per bunch crossing	~2200(1300 with cut)	~2700
Max. Occupancy VXD	2.2e-4	4.1e-4
Max. Occupancy ITK-B		3.8e-5
Max. Occupancy ITK-E	2.5e-4(Single contributes)	2.3e-4

Loss Map at the IR @ Low-Lumi Z

- Single Beam only
- Errors implemented
  - High order error for magnets
  - Beam-beam effect

$$Loss\ Rate = \frac{Loss\ Number}{Loss\ Time} = \frac{Bunch\ number * Particles\ per\ Bunch * (1 - e^{-1})}{Beam\ Lifetime}$$





Loss Map at the IR @ Low-Lumi Z

- Single Beam only
- Errors implemented
  - High order error for magnets
  - Beam-beam effect
- Assume that the beam lifetime is same as High-Lumi Z

$$Loss\ Rate = \frac{Loss\ Number}{Loss\ Time} = \frac{Bunch\ number * Particles\ per\ Bunch * (1 - e^{-1})}{Beam\ Lifetime}$$

	10MW Z, 69ns/BX
Pair Production	~3.2GHz in IR
Beam Thermal Photon	~3.4MHz/beam in IR
Beam Gas Bremsstrahlung	~2.5MHz/beam in IR
Beam Gas Coulomb	~272MHz/beam in IR
Touschek Scattering	~62MHz/beam in IR

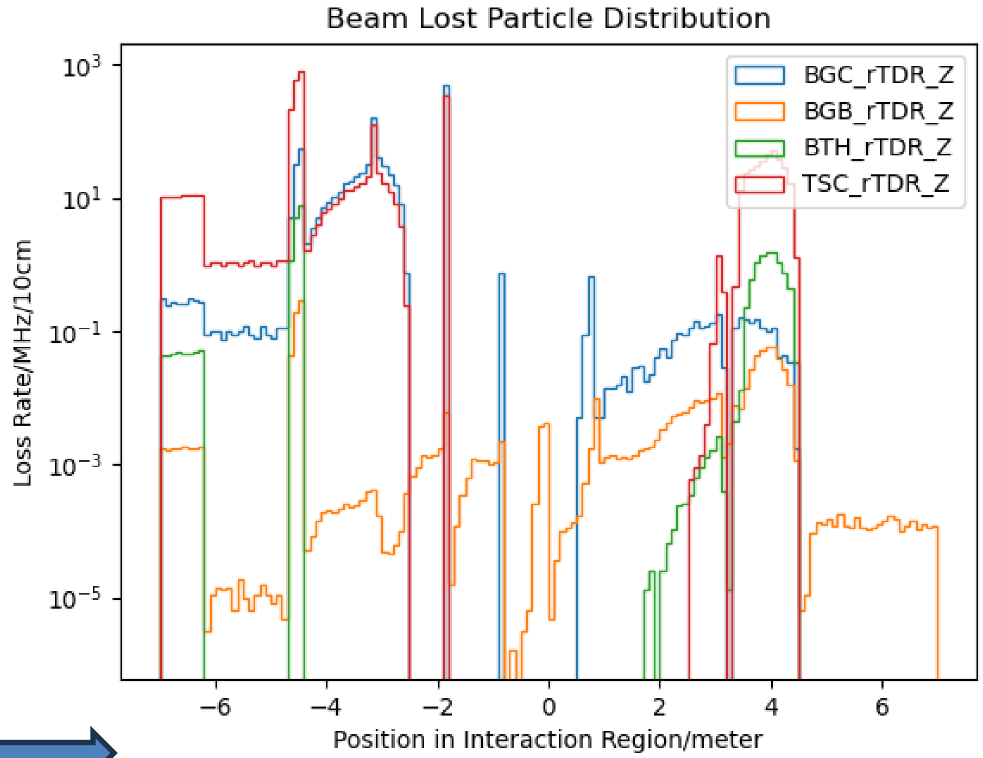
→

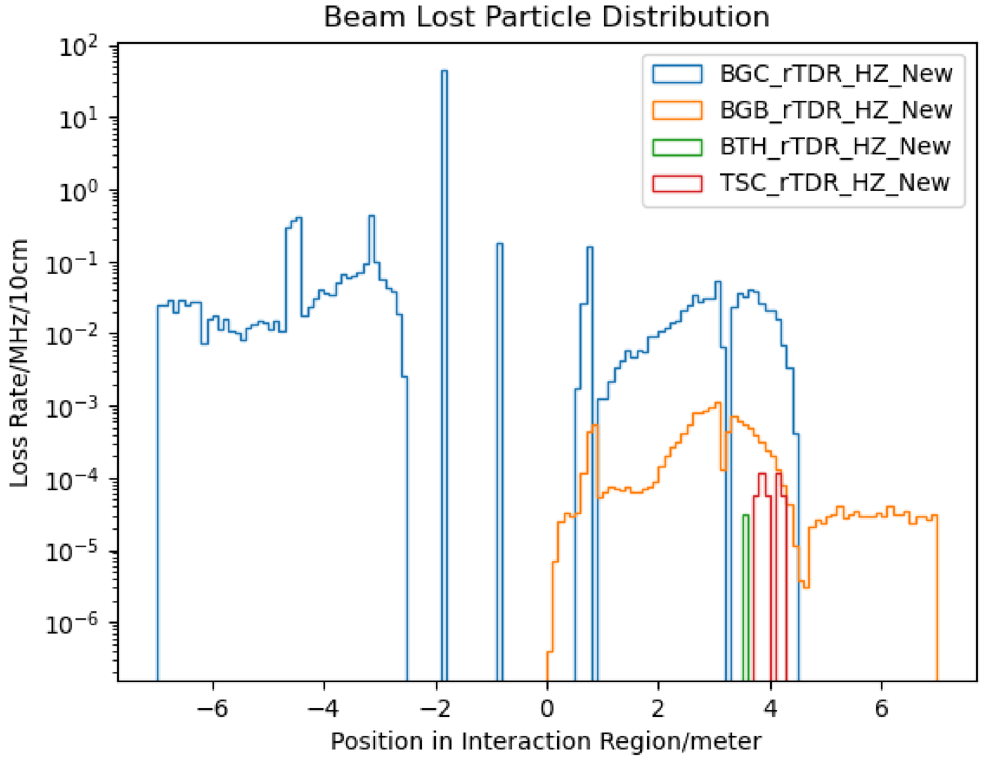
	10MW Z, 69ns/BX
Pair Production	~3.2GHz in IR
Beam Thermal Photon	~24.83 Hz/beam in IR
Beam Gas Bremsstrahlung	~17.9 kHz/beam in IR
Beam Gas Coulomb	~20.8 MHz/beam in IR
Touschek Scattering	~1.3 kHz/beam in IR

Loss Map at the IR @ High-Lumi Z

- Single Beam only
- Errors implemented
  - High order error for magnets
  - Beam-beam effects

$$Loss\ Rate = \frac{Loss\ Number}{Loss\ Time} = \frac{Bunch\ number * Particles\ per\ Bunch * (1 - e^{-1})}{Beam\ Lifetime}$$





Beam Way

Loss Map at the IR @ High-Lumi Z

- Single Beam only
- Errors implemented
  - High order error for magnets
  - Beam-beam effect
- Assume that the beam lifetime is same as High-Lumi Z

$$Loss\ Rate = \frac{Loss\ Number}{Loss\ Time} = \frac{Bunch\ number * Particles\ per\ Bunch * (1 - e^{-1})}{Beam\ Lifetime}$$

	50MW Higgs, 23ns/BX
Pair Production	~25.5GHz in IR
Beam Thermal Photon	~0.26GHz/beam in IR
Beam Gas Bremsstrahlung	~0.01GHz/beam in IR
Beam Gas Coulomb	~2.36GHz/beam in IR
Touschek Scattering	~6.24GHz/beam in IR

→

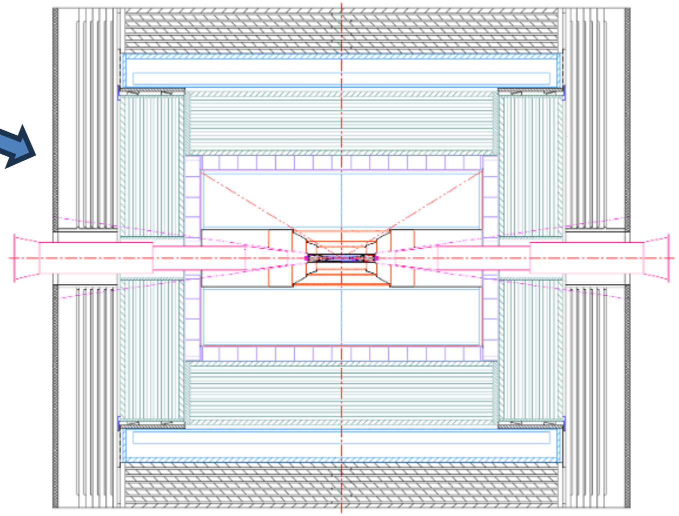
	50MW Higgs, 23ns/BX
Pair Production	~25.5GHz in IR
Beam Thermal Photon	~0.1 kHz/beam in IR
Beam Gas Bremsstrahlung	~0.007 GHz/beam in IR
Beam Gas Coulomb	~0.2 GHz/beam in IR
Touschek Scattering	~1.6 kHz/beam in IR

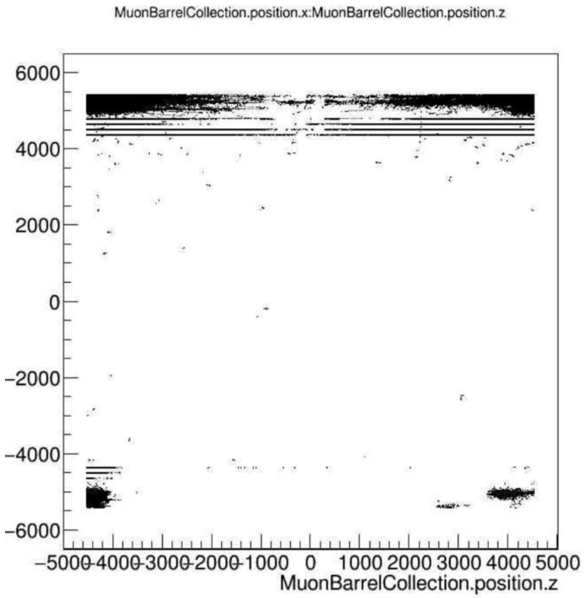
Shielding using Paraffine

- We are adding 10cm paraffine at both ends of the yoke.
  – Current results show that it do help.

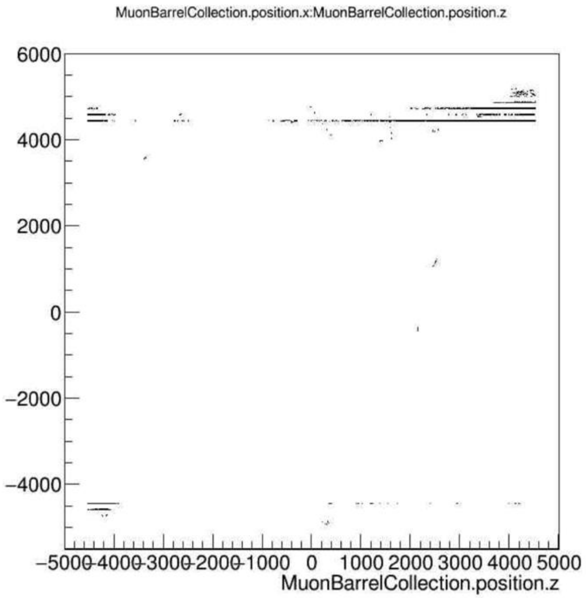
Haopeng Li

Paraffin





No Paraffin Endcap

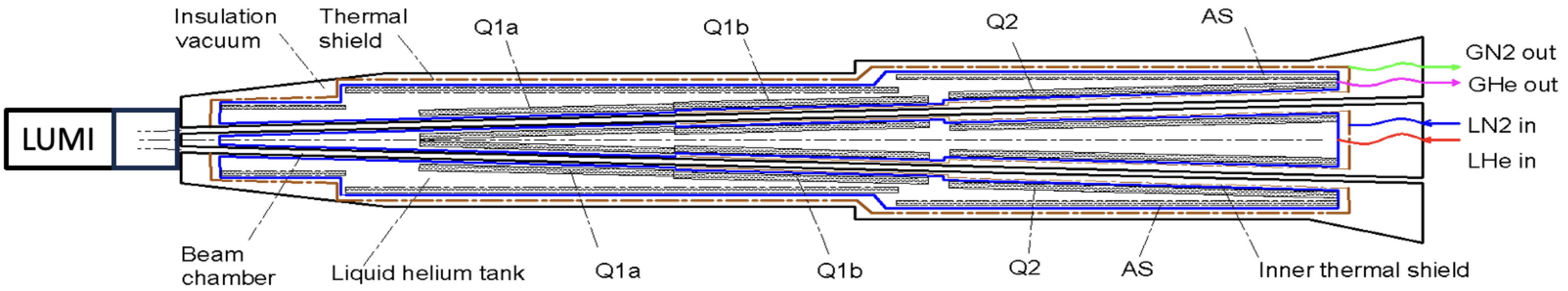


With Paraffin Endcap

Shielding using Heavy Metals outside of Cryo-Module

- 10mm Tungsten added between 800~1050mm
  - The position of the second part of Lumi LYSO has been changed to 800~950mm, followed by BPM at both pipes with a length of 100mm in total.
- Due to the shrinking of the material of the Cryo-module and magnets, we need to add more shielding to mitigate the BIB.
- Currently, we have 2 versions:
  - 5mm Ti(Cryo-Shell) + 10mm W
  - 15mm Stainless-Steel

Xiangzhen Zhang, Xiaochen Yang



Estimation of Impacts in the MDI @ Higgs

- We have obtained a preliminary estimate of the beam-induced background levels in Higgs mode
  - Assume an operational time of 7000hr/yr, time window: 10BX(~3us)

Hancen Lu, Xin She, Zhan Li,
Xiaojie Jiang, Weizheng Song,
Haopeng Li,
Renjie Ma

Sub-Detectors	Ave. Hit Rate(MHz/cm²)		Max. Hit Rate(MHz/cm²)	
	15mm SS	5mm Ti + 10mm W	15mm SS	5mm Ti + 10mm W
Vertex	1.07	1.06	1.19	1.22
ITK	0.00552	0.00545	0.01608	0.01810
TPC	0.0037/pixel	0.0028/pixel	0.012/pixel	0.008/pixel
OTK – Endcap				
ECal –B/E(in cell)	0.011/0.045	0.007/0.023	0.424/2.8	0.172/1.7
HCal – B/E(in cell)	0.0002/0.0053	0.0002/0.0038	0.0058/0.0035	0.221/0.129
Muon – Endcap				
LumiCal – Crystal	1.07	1.07	3.44	3.39

Estimation of Impacts in the MDI @ Low-Z

- We have obtained a preliminary estimate of the beam-induced background levels in Low Lumi Z mode
  - Assume an operational time of 7000hr/yr, time window: 10BX(~3us)

Hancen Lu, Xin She, Zhan Li,
Xiaojie Jiang, Weizheng Song,
Haopeng Li,
Renjie Ma

Sub-Detectors	Ave. Hit Rate(MHz/cm²)		Max. Hit Rate(MHz/cm²)	
	15mm SS	5mm Ti + 10mm W	15mm SS	5mm Ti + 10mm W
Vertex	5.52	5.49	9.56	9.39
ITK	0.0122	0.0120	0.0499	0.0546
TPC	0.006/pixel	0.004/pixel	0.018/pixel	0.013/pixel
OTK – Endcap				
ECal –B/E(in cell)	0.015/0.065	0.011/0.035	0.335/6.7	0.212/2.4
HCal – B/E(in cell)	0.0007/0.0082	0.0007/0.006	0.012/0.249	0.012/0.157
Muon – Endcap				
LumiCal – Crystal	49.89	50.12	130.67	131.88

Estimation of Impacts in the MDI @ High-Z

- We have obtained a preliminary estimate of the beam-induced background levels in High Lumi Z mode
  - Assume an operational time of 7000hr/yr, time window: 10BX(~3us)

Hancen Lu, Xin She, Zhan Li,
Xiaojie Jiang, Weizheng Song,
Haopeng Li,
Renjie Ma

Sub-Detectors	Ave. Hit Rate(MHz/cm^2)		Max. Hit Rate(MHz/cm^2)	
	15mm SS	5mm Ti + 10mm W	15mm SS	5mm Ti + 10mm W
Vertex	27.04	27.06	41.03	40.51
ITK	0.106	0.103	0.4884	0.5353
TPC				
OTK – Endcap				
ECal –B/E(in cell)	0.077/0.334	0.054/0.187	2.1/34.5	1.1/15.2
HCal – B/E(in cell)	0.0022/0.053	0.0021/0.040	0.044/2.1	0.035/1.4
Muon – Endcap				
LumiCal – Crystal				

Summary & Outlook

- The beam induced backgrounds @ Higgs and Z-pole are updating, together with the mitigation methods
  - The updated collimators look promising. All single beam backgrounds have been mitigated at least one order of magnitude. The optimization is still on going.
  - The dose estimation using FLUKA is on going. We formed a dedicated working group working on this(1 staff from IMMU+ 1 student from NKU).
- We are towards the baseline of the shielding.
  - We compared with 15mm SS(~0.85X_0) and 5mm Ti+10mm W(~2.99X_0). The second one has longer radiation length, might be better in shielding.
  - The shielding effects of the TiW is ~30% better in Ecal/TPC, almost same at other sub-detectors.
  - Currently, we could take 15mm SS as baseline. Our accelerator colleagues also performed a study on deformation based on this design and will be presented this afternoon.

Summary & Outlook

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Thank You

Backup

Simulation Workflow

Could get the step information at sub-detectors
Implemented time window, 1BX/3BX for higgs

Merge the steps into cell

More Shielding

- Adding 40mm Tungsten between 1110~1900mm

Weizheng Song

  – More shielding is better, that indicates us we might find some methods to mitigate more.

时间窗为bunch spacing 346 / 9 / 23 ns 阈值为0.1mip			平均计数率 [KHz/cell]	最大计数率 [KHz/cell]	最大占空比 [%]
带有4cm W以前的结果	ECAL Barrel	Higgs	4	87	---
		LZ	43	1,130	---
	ECAL Endcap	Higgs	9	469	---
		LZ	66	1,368	---

	ECAL Barrel	Higgs	7	172	0.44
		LZ	11	212	0.16
		HZ	54	1,065	0.2
	ECAL Endcap	Higgs	23	1,746	1.74
		LZ	35	2,408	0.39
		HZ	187	15,209	0.57
15mm Ti+W		[illegible]	[illegible]	[illegible]	[illegible]