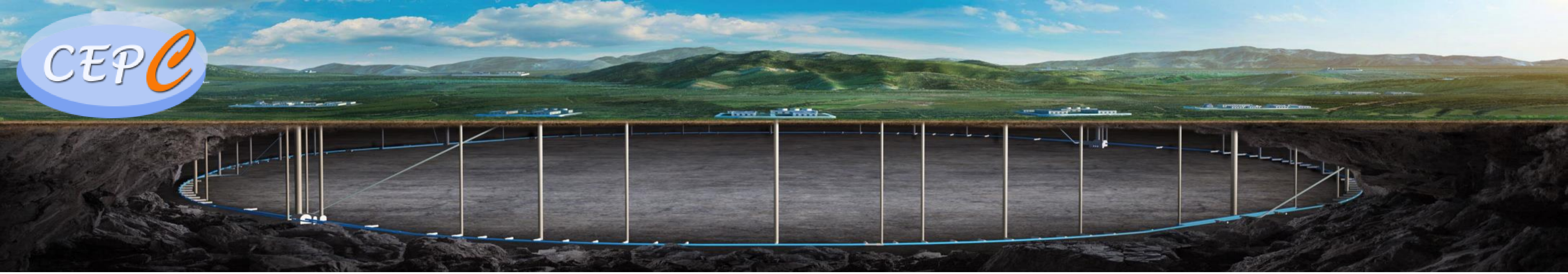


CEPC Beam Backgrounds Status

Haoyu SHI
(On behalf of the CEPC MDI Working Group)

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Nov. 27th, 2024, CEPC Day

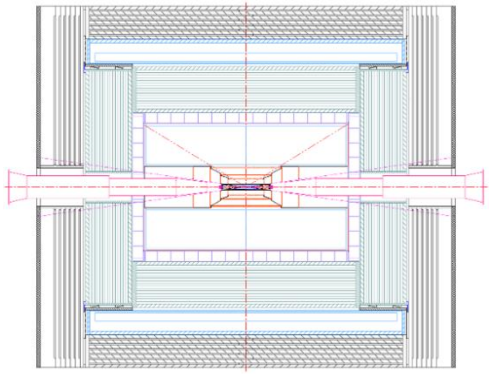
Content

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

Introduction

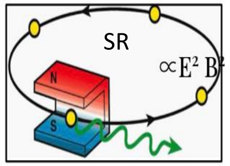
- Reasonable Estimation of Beam-induced background levels
  - Based on the 50-MW design of CEPC Accelerator TDR
  - Keep updating with the Ref-TDR detector
  - Higgs, Z, W, ttbar
- Estimation of the Noise on Detector due to Backgrounds, Normal Operation
  - Hit Rate/Occupancy
- Estimation of the Radiation 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	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	50			
Half crossing angle at IP (mrad)	16.5			
Bending radius (km)	10.7			
Energy (GeV)	120	45.5	80	180
Energy loss per turn (GeV)	1.8	0.037	0.357	9.1
Damping time $\tau_x/\tau_y/\tau_z$ (ms)	44.6/44.6/22.3	816/816/408	150/150/75	13.2/13.2/6.6
Piwinski angle	4.88	29.52	5.98	1.23
Bunch number	446	13104	2162	58
Bunch spacing (ns)	355 (53% gap)	23 (10% gap)	154	2714 (53% gap)
Bunch population (10^{11})	1.3	2.14	1.35	2.0
Beam current (mA)	27.8	1340.9	140.2	5.5
Phase advance of arc FODO (°)	90	60	60	90
Momentum compaction (10^{-5})	0.71	1.43	1.43	0.71
Beta functions at IP β_x^*/β_y^* (m/mm)	0.3/1	0.13/0.9	0.21/1	1.04/2.7
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Betatron tune ν_x/ν_y	445/445	317/317	317/317	445/445
Beam size at IP σ_x/σ_y (um/nm)	14/36	6/35	13/42	39/113
Bunch length (natural/total) (mm)	2.3/4.1	2.7/10.6	2.5/4.9	2.2/2.9
Energy spread (natural/total) (%)	0.10/0.17	0.04/0.15	0.07/0.14	0.15/0.20
Energy acceptance (DA/RF) (%)	1.6/2.2	1.0/1.5	1.05/2.5	2.0/2.6
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.0045/0.13	0.012/0.113	0.071/0.1
RF voltage (GV)	2.2	0.1	0.7	10
RF frequency (MHz)	650			
Longitudinal tune ν_s	0.049	0.032	0.062	0.078
Beam lifetime (Bhabha/beamstrahlung) (min)	40/40	90/930	60/195	81/23
Beam lifetime requirement (min)	20	81	25	18
Hourglass Factor	0.9	0.97	0.9	0.89
Luminosity per IP (10^{34} cm^{-2} s^{-1})	8.3	192	26.7	0.8

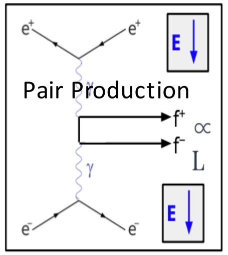


Sources and Simulation Tools

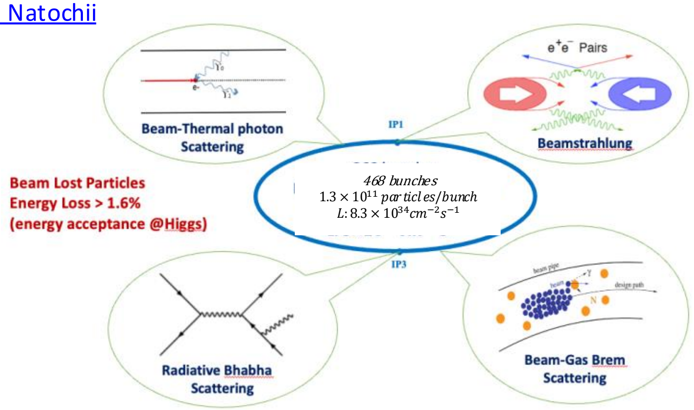
- Single Beam
  - Touschek Scattering
  - Beam Gas Scattering(Elastic/inelastic)
  - Beam Thermal Photon Scattering
  - Synchrotron Radiation
- Luminosity Related
  - Beamstrahlung
  - Radiative Bhabha Scattering
- Injection(Will be considered future)



A. Natochii

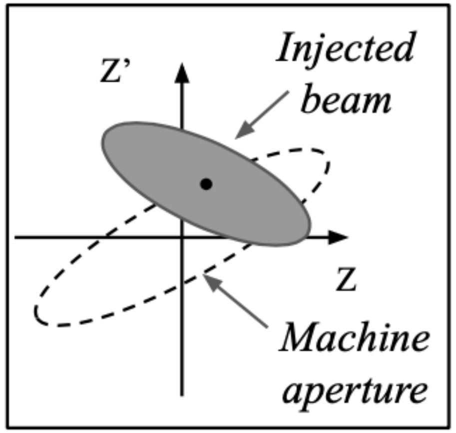


Photon BG



Beam Loss BG

A. Natochii



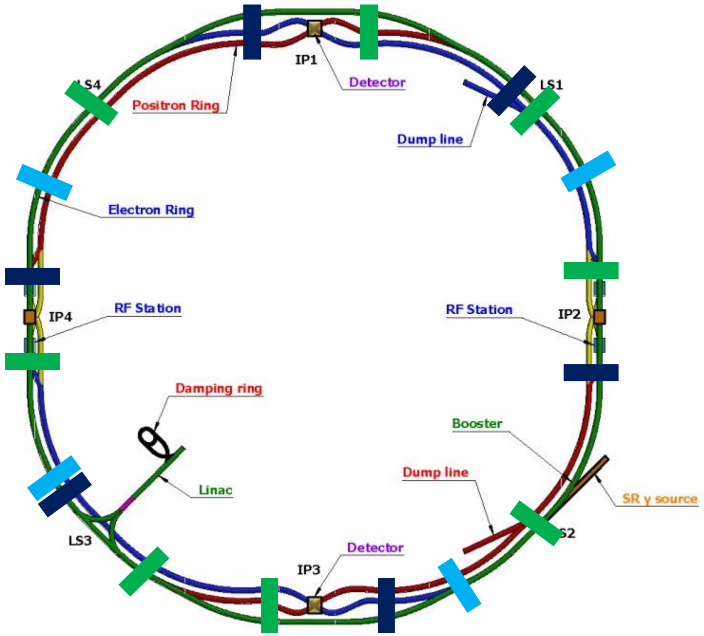
Injection BG

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		

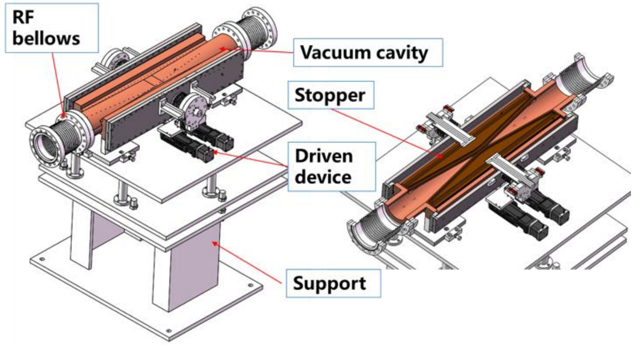
Collimators

- Collimators were implemented to reduce IR loss caused by single beam.
  - 16 sets of collimators were implemented for MDI purpose
  - ~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

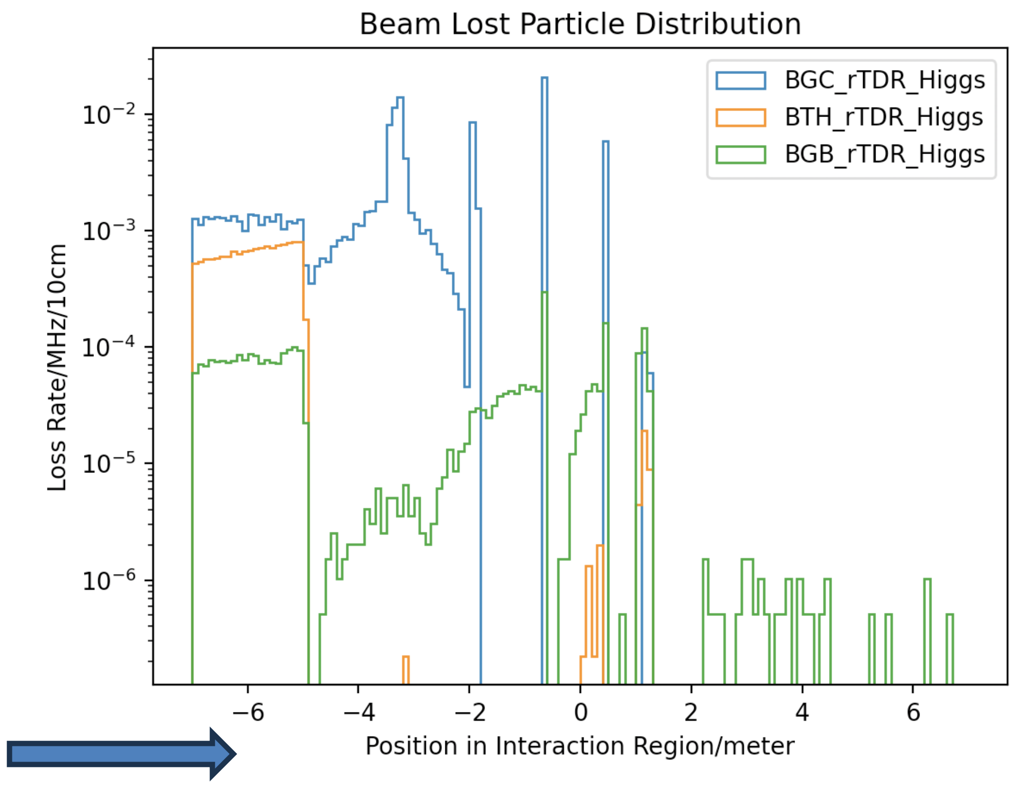
for momentum collimator

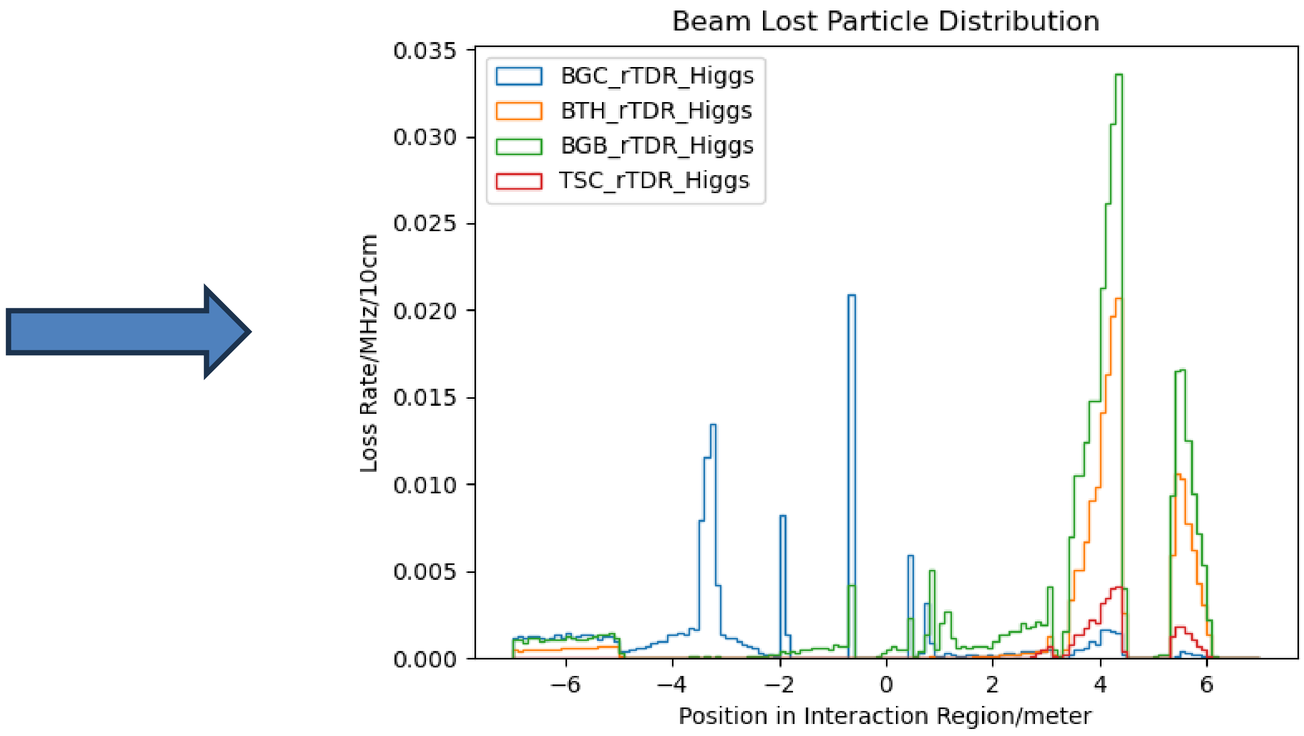
for vertical collimator

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	~0.36MHz/beam in IR
Beam Gas Bremsstrahlung	~0.04MHz/beam in IR
Beam Gas Coulomb	~0.24MHz/beam in IR

	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
Radiative Bhabha	
SR	~630 PHz/beam generated at last bending magnet

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

Estimation of Impacts in the MDI

- We have obtained a preliminary estimate of the beam-induced background levels in Higgs mode
  - Assume an operational time of 7000hr/yr
  - TDR_o1_v01_20241018, time window: 10BX(~3us)

Hancen Lu, Xin She, Zhan Li, Dian Yu, Weizheng Song, Haopeng Li, Renjie Ma

Sub-Detectors	Ave. Hit Rate(MHz/cm2)	Max. Hit Rate(MHz/cm^2)	Max. Occupancy/BX(%)	Ave. TID(Gy/yr)
Vertex	0.49	0.61	0.0022	~21000
ITK	0.0021	0.25	0.025(Strip)	128
TPC	2.7	6.0	0.0045	23.4(Supporting)
OTK – Endcap	0.0002	0.0006	0.35(Strip)	6.95
ECal – Endcap	0.011/bar	0.3/bar	0.0008	0.322
HCal – Endcap	0.002/GS	0.05/GS	0.0005	0.044
Muon – Endcap	0.00000001/cell	0.00002/cell	0.006	0.21
LumiCal – Crystal	3.37	7.82	9.1	2610

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

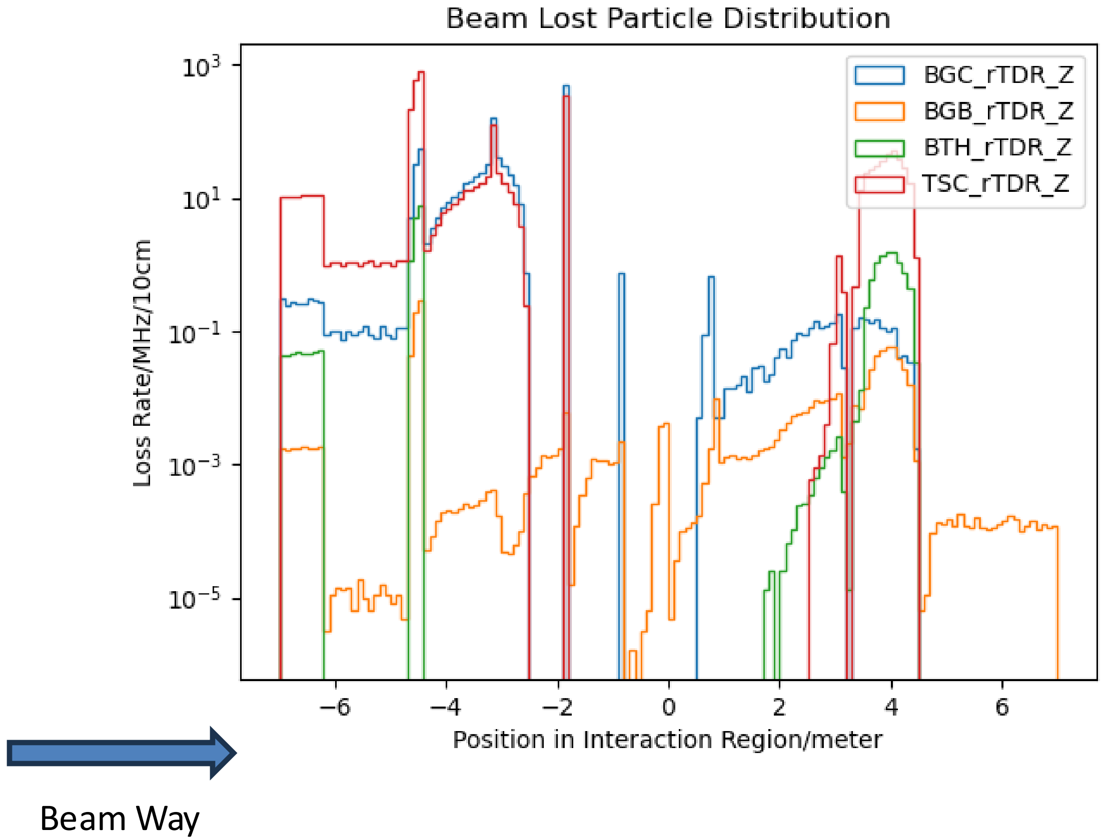
Manuela Boscolo, Andrea Ciarma

	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 @ High-Lumi Z

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

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



	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

Estimation of Impacts in the MDI

- We have obtained a preliminary estimate of the beam-induced background levels in High Lumi Z mode

Hancen Lu, Xin She, Zhan Li,
Dian Yu, Weizheng Song, Haopeng Li

  – TDR_o1_v01_20241018, time window(1BX, 23ns)

Sub-Detectors	Ave. Hit Rate(MHz/cm2)	Max. Hit Rate(MHz/cm^2)	Max. Occupancy/BX(%)	TID(Gy/yr)
Vertex	15.64	18.34	3.73e-3	
ITK	0.61	57.61	0.0543	
TPC	2	3.5	0.0026	
OTK – Endcap				
Ecal – Barrel	1.54/bar	22.3/bar	7.03	
ECal – Endcap	2.84/bar	43.5/bar	9.29	
HCal – Endcap				
Muon – Endcap			1.5	
LumiCal – Crystal				

Current Parameters of Low-Lumi Z

	Z (3T)	
Number of IPs	2	
Circumference (km)	100	
SR power per beam (MW)	8.7	12.1
Half crossing angle at IP (mrad)	16.5	
Bending radius (km)	10.7	
Energy (GeV)	45.5	
Energy loss per turn (GeV)	0.037	
Damping time $\tau_x/\tau_y/\tau_z$ (ms)	816/816/408	
Piwinski angle	24	
Bunch number	3978	
Bunch spacing (ns)	69.2	
Bunch population (10^{11})	1.22	1.7
Beam current (mA)	233.2	325.0
Phase advance of arc FODO (°)	**90**	**60**
Momentum compaction (10^{-5})	0.71	1.43
Beta functions at IP β_x^*/β_y^* (m/mm)	0.2/1.0	0.13/1.0
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.092/1.7	0.27/5.1
Betatron tune ν_x/ν_y	445/445	317/317
Beam size at IP σ_x/σ_y (um/nm)	4/42	6/72
Bunch length (natural/total) (mm)	2.1/8.3	2.5/8.8
Energy spread (natural/total) (%)	0.04/0.11	0.04/0.13
Energy acceptance (DA/RF) (%)	1.0/1.9	1.0/1.7
Beam-beam parameters ξ_x/ξ_y	0.0065/0.11	0.0053/0.082
RF voltage (GV)	0.09	0.12
RF frequency (MHz)	650 (2 cell cavity)	
Longitudinal tune ν_s	0.021	0.035
Beam lifetime (Bhabha/beamstrahlung) (min)	120/200	150/180
Beam lifetime requirement (min)	68	
Hourglass Factor	0.97	
Luminosity per IP (10^{34} cm^{-2} s^{-1})	24	26

Dou Wang

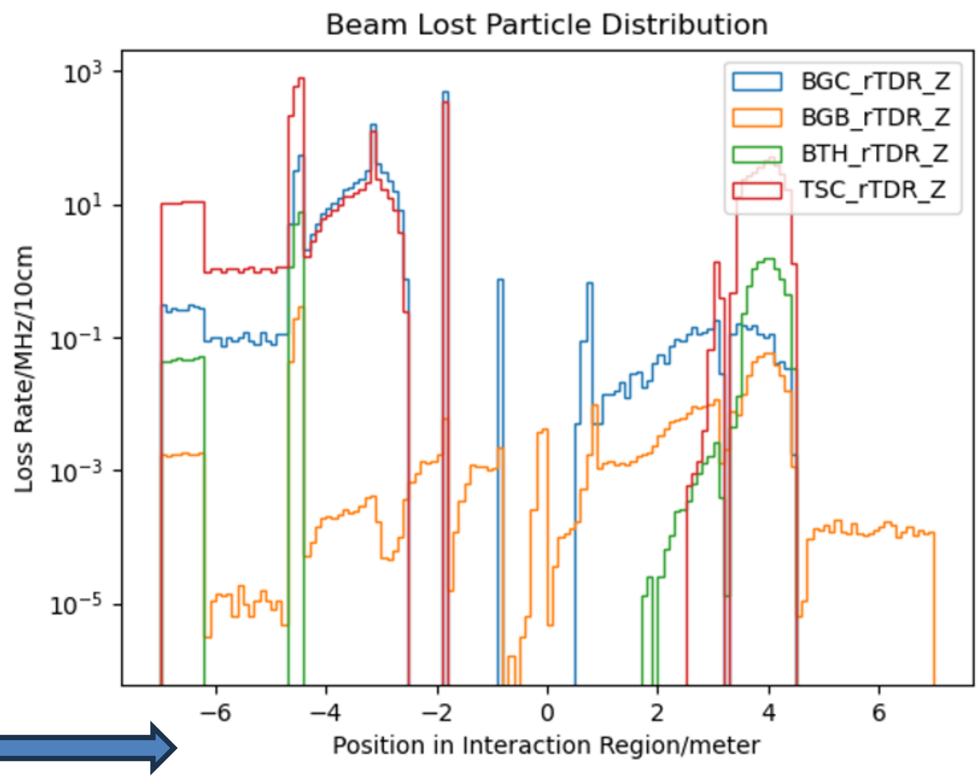
- Higgs lattice: 90°
- Z lattice: 60°

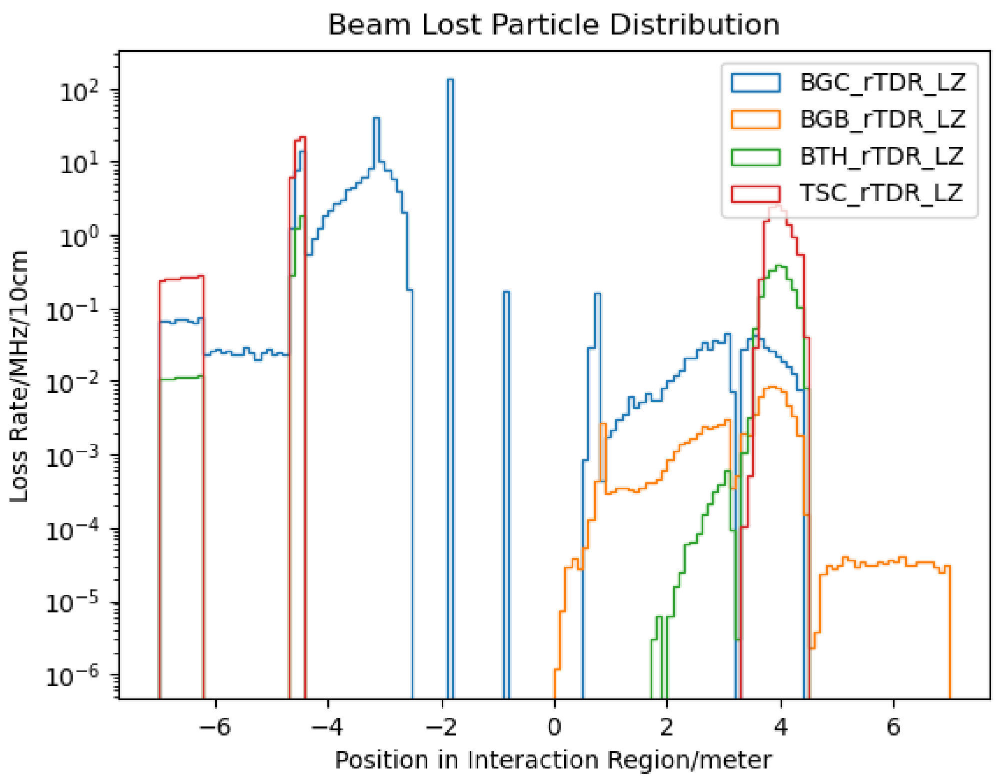
~1/8 comparing with High-Lumi Z

Loss Map at the IR @ Low-Lumi Z

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

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





Beam Way

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

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

	50MW Z, 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

→

	10MW Z, 69ns/BX
Pair Production	~3.2GHz in IR
Beam Thermal Photon	~63MHz/beam in IR
Beam Gas Bremsstrahlung	~2.5MHz/beam in IR
Beam Gas Coulomb	~272MHz/beam in IR
Touschek Scattering	~62MHz/beam in IR

Loss Rate much lower than 1/8

Both because of parameter change and the correction on emittance Y in SAD

Estimation of Impacts in the MDI

- We have obtained a preliminary estimate of the beam-induced background levels in Low Lumi Z mode using scale
  – TDR_o1_v01_20241018, time window(1BX, 23ns), scaling factor 0.125

Hancen Lu, Xin She, Zhan Li, Dian Yu, Weizheng Song, Haopeng Li

Sub-Detectors	Ave. Hit Rate(MHz/cm2)	Max. Hit Rate(MHz/cm^2)	Max. Occupancy/BX(%)	Ave. TID(Gy/yr)
Vertex	1.96	2.30	3.73e-3	
ITK	0.08	7.20	0.0543	
TPC	0.25	0.45	0.0026	
OTK – Endcap				
ECal – Barrel	0.2	2.79/bar	7.03	
ECal – Endcap	0.35	5.44/bar	9.29	
HCal – Endcap				
Muon – Endcap			1.5	
LumiCal – Crystal				

Shielding of the Detectors

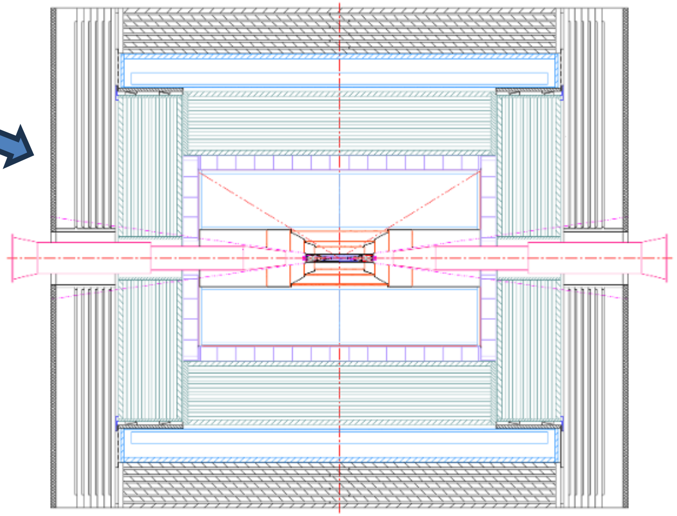
- The sources of the BG has two groups:
  - From IP, luminosity related(pair-production, radiative Bhabha)
  - From anywhere around the ring, less in IP(single beam losses and SR)
- Previously, we have several methods of shielding(or mitigation)
  - Using collimators to block single beam loss outside 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

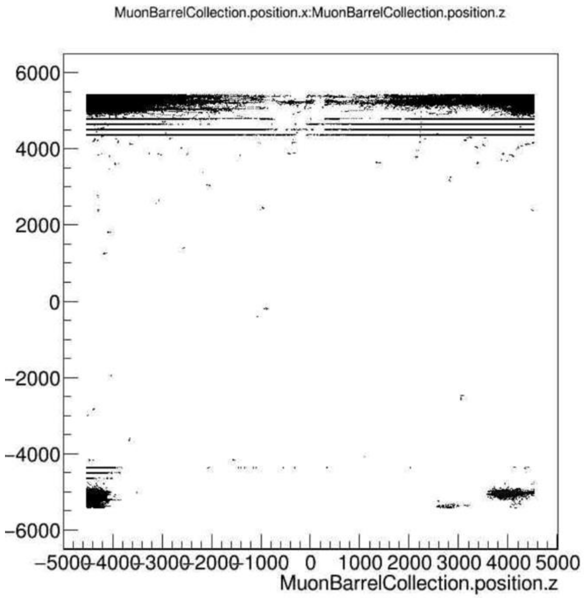
Shielding Effects of Paraffine

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

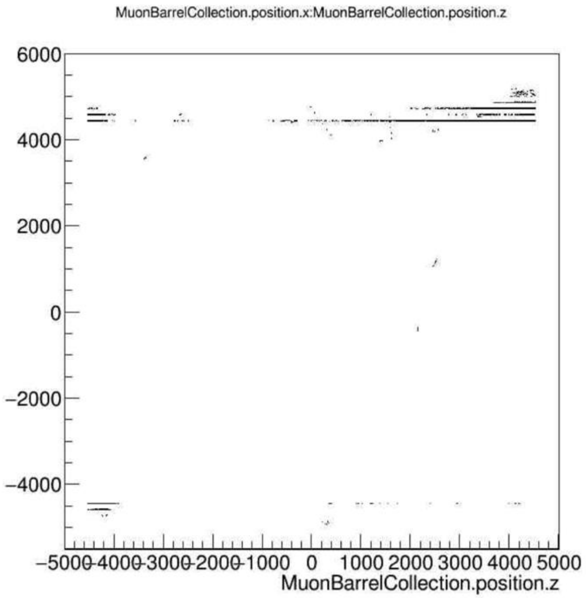
Haopeng Li

Paraffin





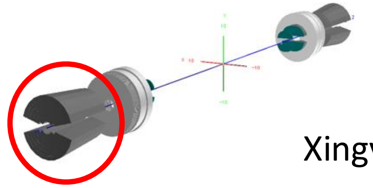
No Paraffin Endcap



With Paraffin Endcap

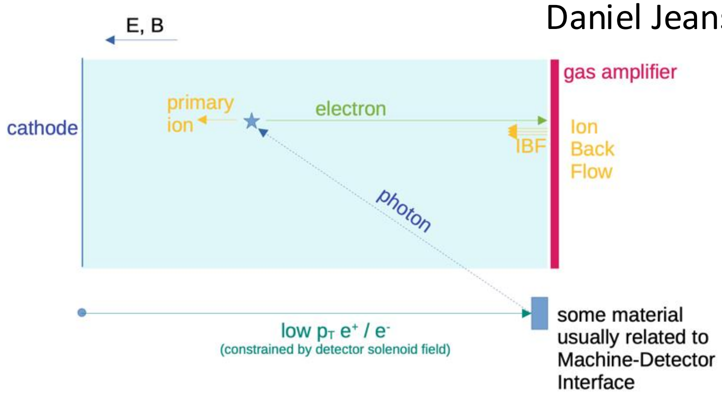
Shielding Effects of Tungsten

- After fixing the threshold @ TPC, we need to find some space for shielding.
- Currently, we have several attempts, including
  - Add 1cm/2cm tungsten shielding outside of the cryo-module
  - Change all the crystal (900-1100 of LumiCal) to tungsten for testing
  - Therefore, we have 5 versions
    - Crystal Lumi + No tungsten outside cryomodule
    - Crystal Lumi + 1cm tungsten outside cryomodule
    - Crystal Lumi + 2cm tungsten outside cryomodule
    - Tungsten Lumi + 1cm tungsten outside cryomodule
    - High Z Pipe + Crystal Lumi + 1cm tungsten outside cryomodule
- The shielding would impact ITK/TPC/OTK/Calo



Xingyang Sun

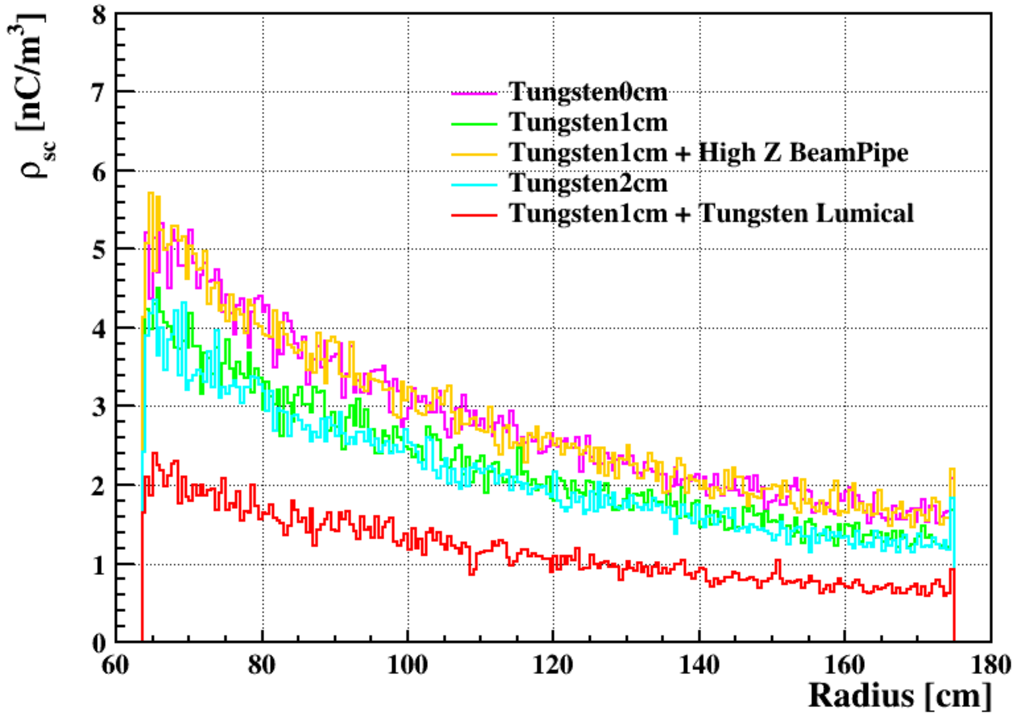
Daniel Jeans



Shielding Effects @ TPC

- We have preliminary version on TPC.
- In general, wlumi>w2cm>w1cm>highzpipe/w0cm

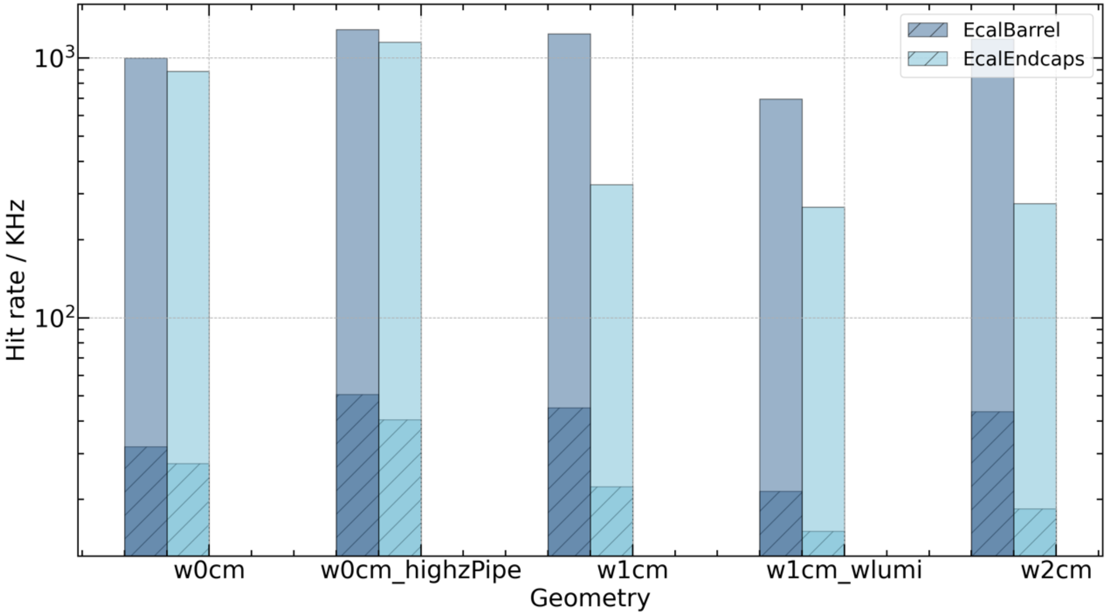
Xin She

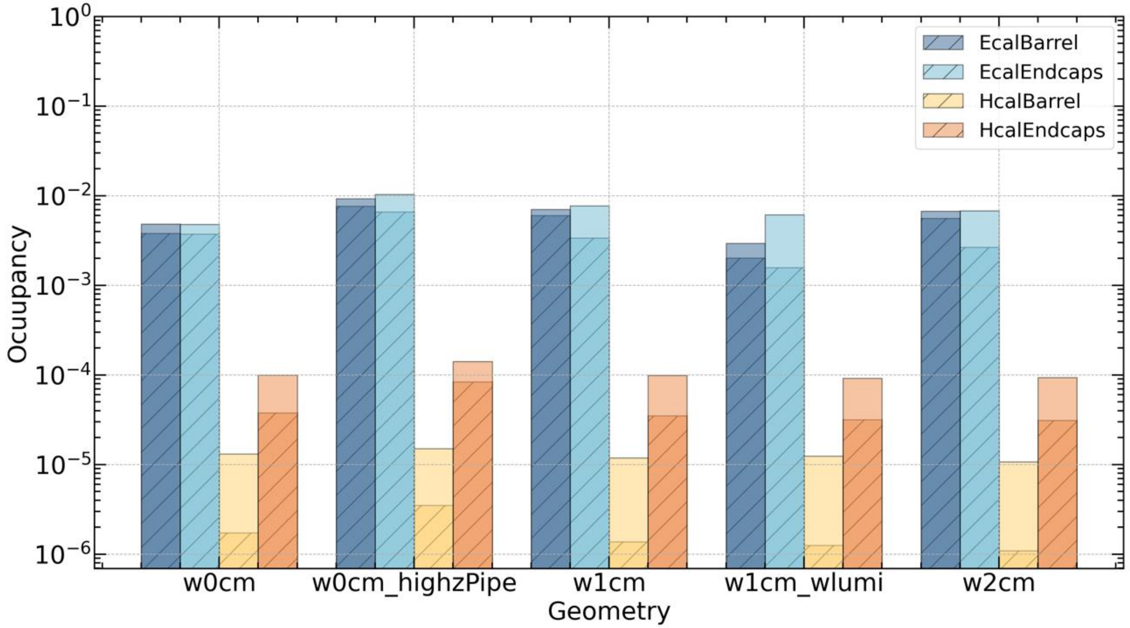


Shielding Effects @ Calo

- We have preliminary version on both hit rate and occupancy, including ecal and hcal.
- For barrel, wlumi>w0cm>w2cm>w1cm>highzpipe
- For endcap, wlumi>w2cm>w1cm>w0cm>highzpipe

Weizheng Song





Fast Estimation using full simulation, the scintillation decay time not considered yet

Summary & Outlook

- The beam induced backgrounds @ Higgs and Z-pole are updating. (Priority: Higgs > Low-Z@3T > High-Z)
  - Higgs simulation could be finished this week.
  - Low-Z @ 3T are simulating. High-Z @ 2T needs to re-simulated.
- The study on the effects of shielding is ongoing, we need shielding.
  - The paraffine shielding at both ends of yoke is needed. Software merging.
  - The tungsten shielding outside lumical helps, we need to balance.
  - The tungsten shielding outside cyro-module needs more detailed study.

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