CEPC Beam Induced Background Study

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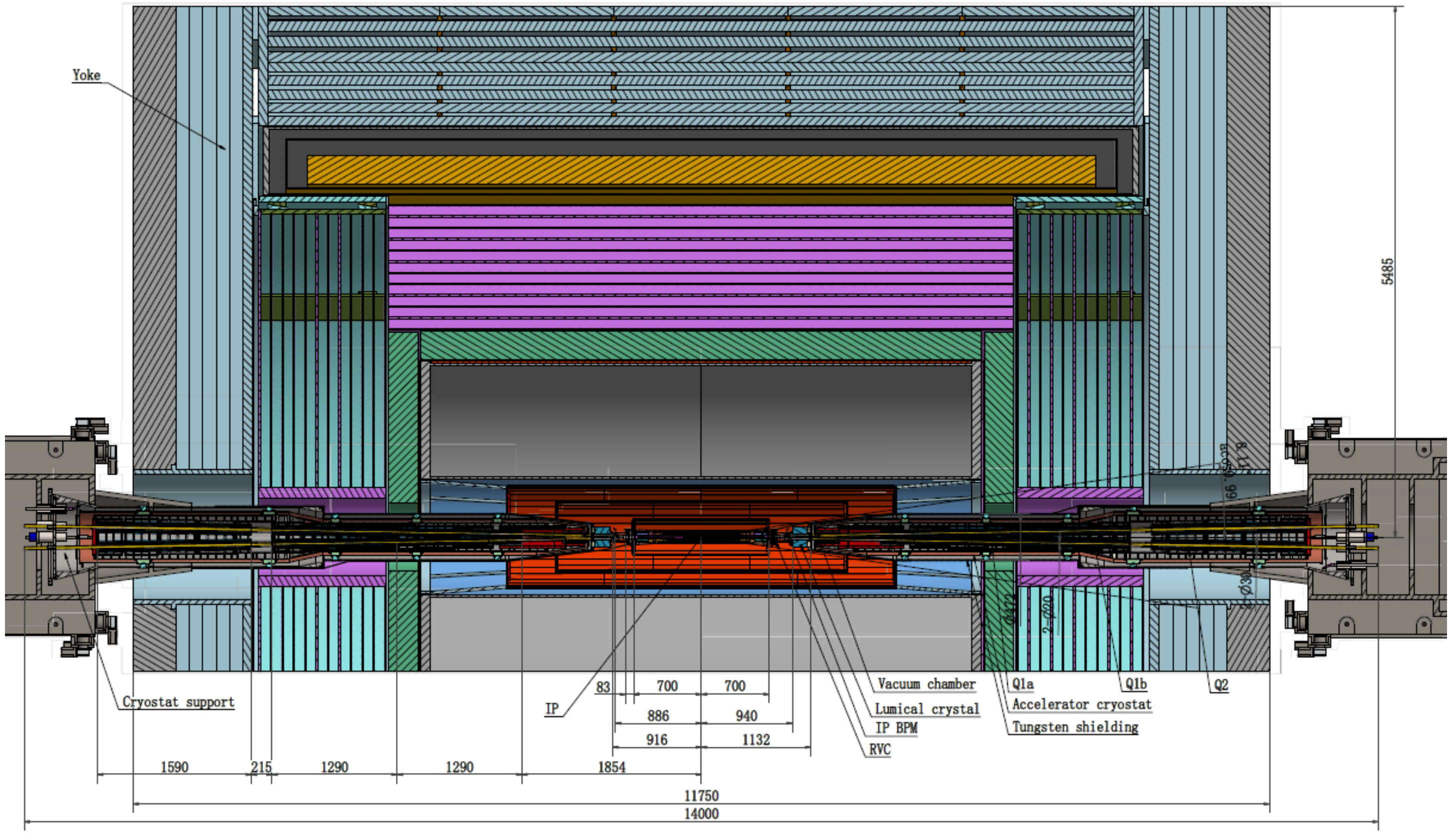
Study Contents of CEPC MDI

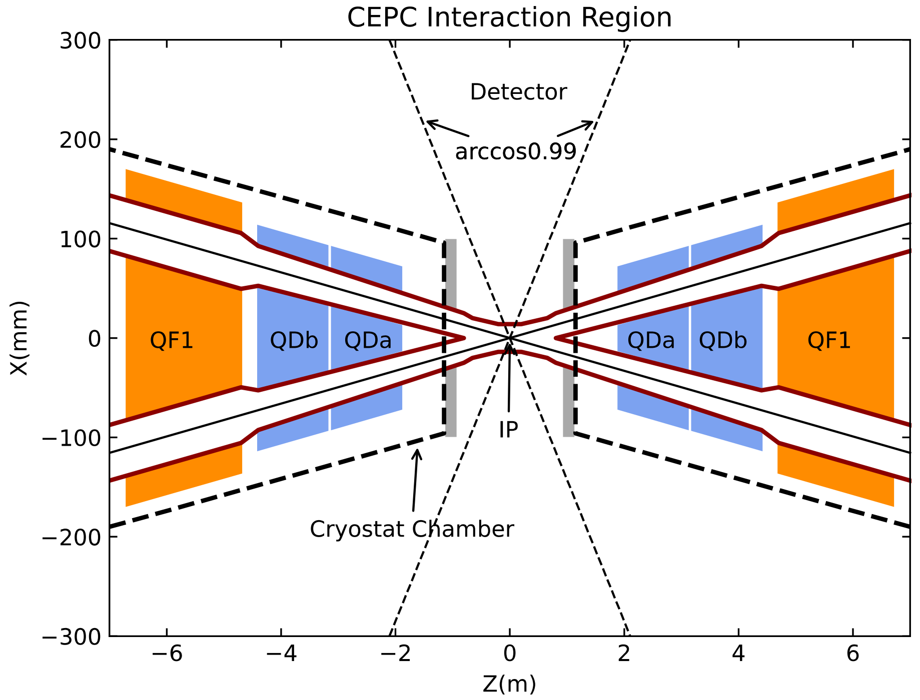
- The Layout of the MDI Region
- The Key Components
  - Beampipe
  - Final Focusing system and supporting modules
- Detectors
  - LumiCal
  - Fast Luminosity Monitor
  - BPMs
- Thermal Analysis
- Beam Induced Backgrounds

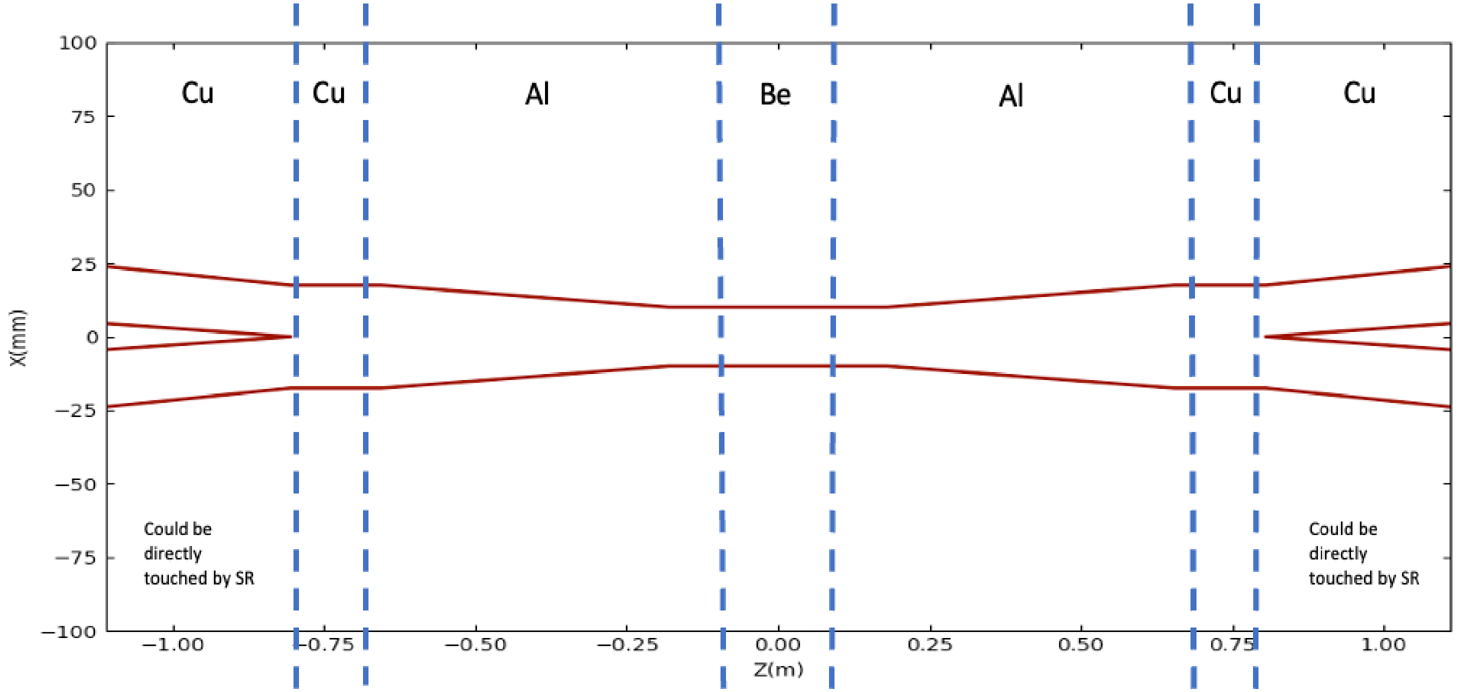


The length of MDI Region is -7m~7m at TDR Phase

Updated MDI Region for CEPC

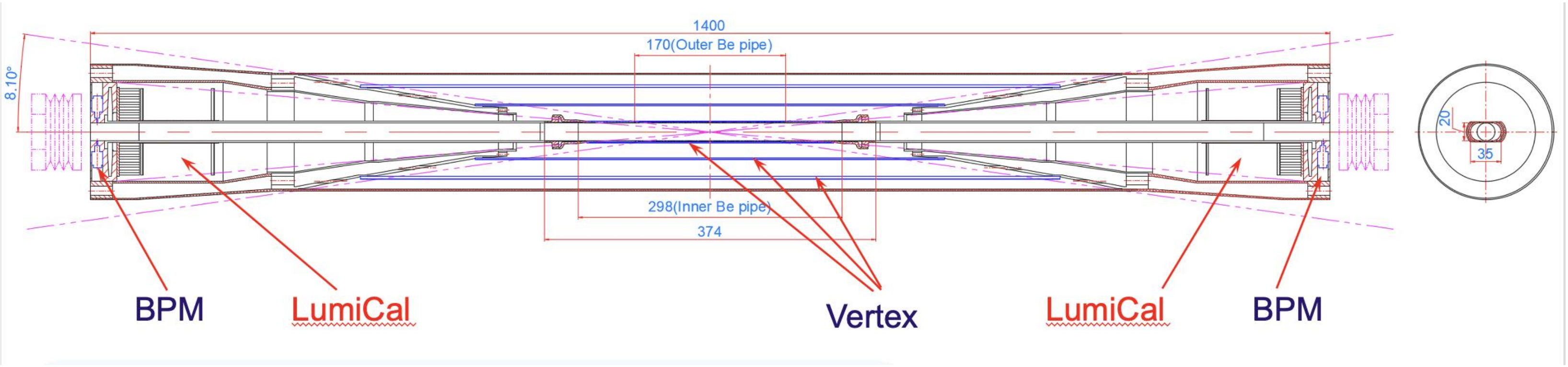
- Interaction Region Layout/Parameters
  - L* = 1.9m / Detector Acceptance = 0.99





Mechanical Design of the detector beam pipe

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



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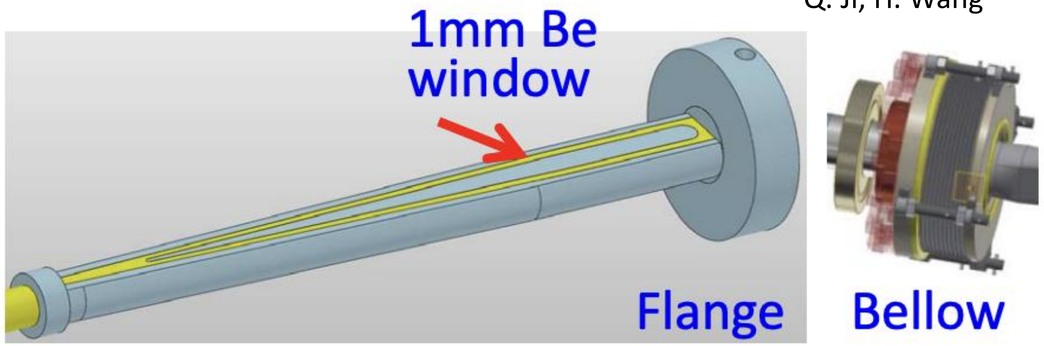
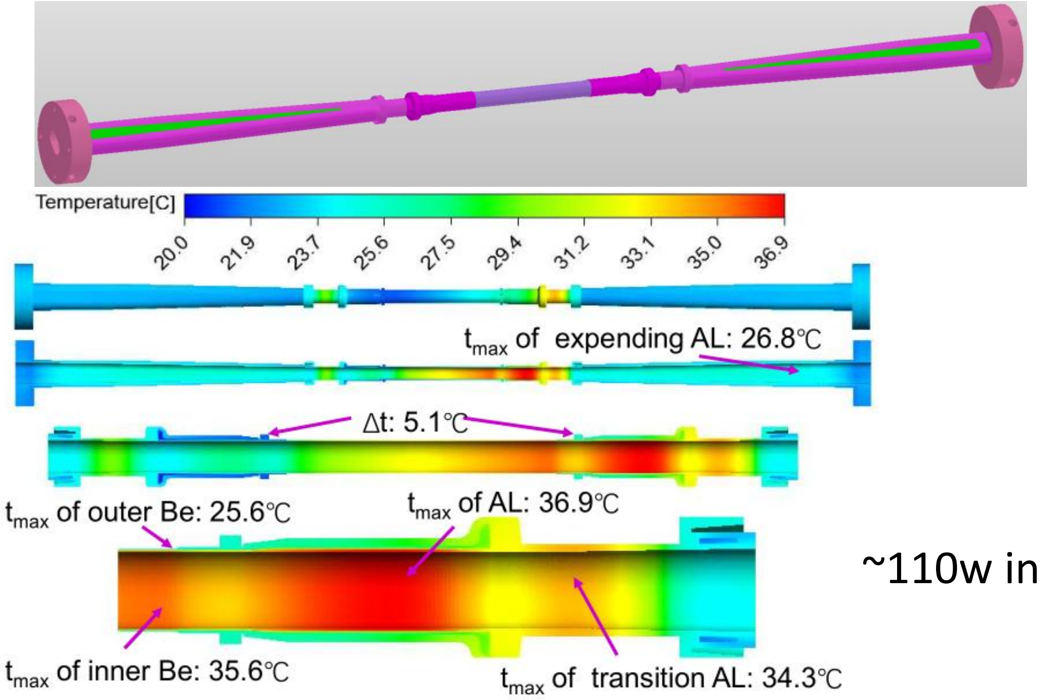


- Water or Paraffin could be used as the coolant
- Preliminary analysis shows that the dynamic temperature/pressure could meet the requirements.



~110w in total

Beam Induced Background

- Reasonable Estimation of Beam-induced background levels
  - Based on the 50-MW design of CEPC Accelerator TDR
  - Keep updating with the Ref-TDR detector
- Estimation of the Noise on Detector
- Estimation of the Radiation Environment: contributions from Backgrounds and Signal
- Mitigation Methods

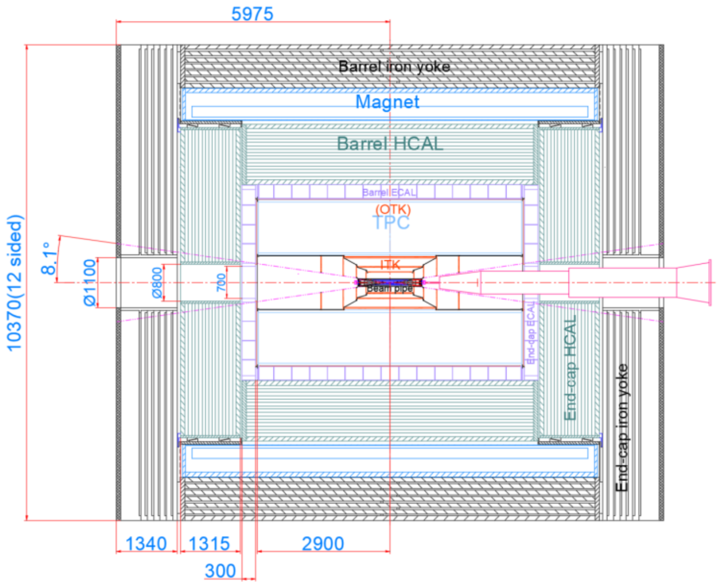


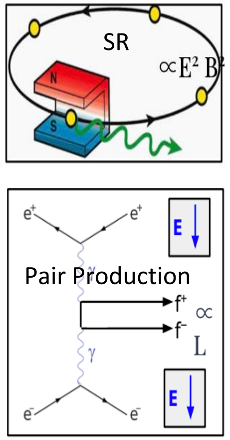
Figure 14.4: MDI Interface Dimension

Table 3.4: Parameters of the CEPC 50MW design

	Higgs	High-Lumi-Z	Low-Lumi-Z
Number of IPs	2		
Solenoid(T)	3		
Circumference (km)	99.955		
Half crossing angle at IP (mrad)	16.5		
Bending radius (km)	10.7		
SR power per beam (MW)	50		12.1
Energy (GeV)	120	45.5	45.5
Energy loss per turn (GeV)	1.8	0.037	0.037
Bunch number	446	13104	3978
Bunch spacing (ns)	277.0	23.1	69.2
[× 23.08 ns]	12	1	3
Train gap [%]	63	9	9
Bunch population (10^{11})	1.3	2.1	1.7
Beam current (mA)	27.8	1345.2	325.0
Beta functions at IP b_x^*/b_y^* (m/mm)	0.3/1	0.2/1.0	0.13/1.0
Emittance e_x/e_y (nm/pm)	0.64/1.3	0.27/5.1	0.27/5.1
Betatron tune n_x/n_y	445/445	317/317	317/317
Beam size at IP s_x/s_y (um/nm)	14/36	6/72	6/72
Bunch length (natural/total) (mm)	2.3/4.1	2.6/9.8	2.5/8.8
Energy spread (natural/total) (%)	0.10/0.17	0.04/0.15	0.04/0.13
Energy acceptance (DA/RF) (%)	1.6/2.2	1.2/1.7	1.0/1.7
Beam-beam parameters x_x/x_y	0.015/0.11	0.0046/0.074	0.0053/0.082
Beam lifetime (Bhabha/beamstrahlung) (min)	40/40	120/280	150/180
Beam lifetime requirement (min)	20	81	68
Luminosity per IP (10^{34} cm^{-2} s^{-1})	8.3	95.2	26

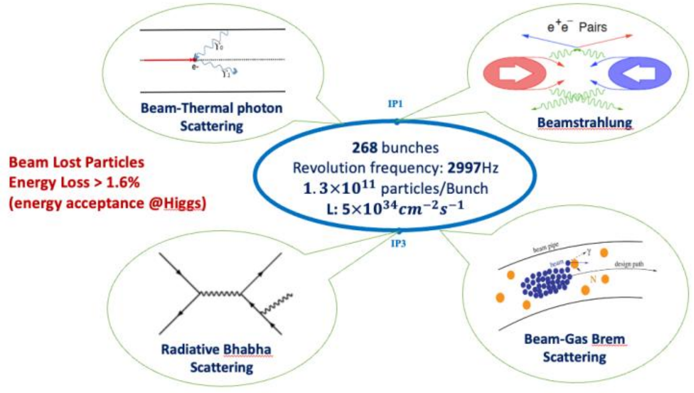
Background Estimation

- Single Beam
  - Touschek Scattering
  - Beam Gas Scattering(Elastic/inelastic)
  - Beam Thermal Photon Scattering
  - Synchrotron Radiation
- Luminosity Related
  - Beamstrahlung
  - Radiative Bhabha Scattering
- Injection(Not Considered yet)



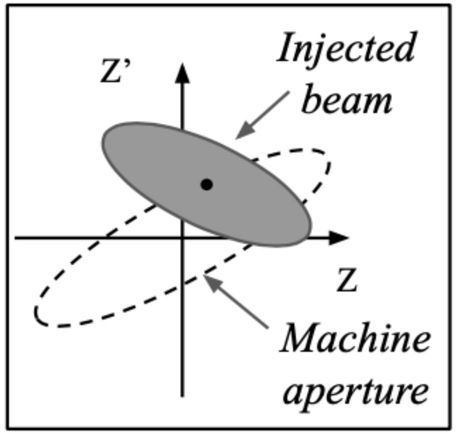
Photon BG

A. Natochii



Beam Loss BG

A. Natochii



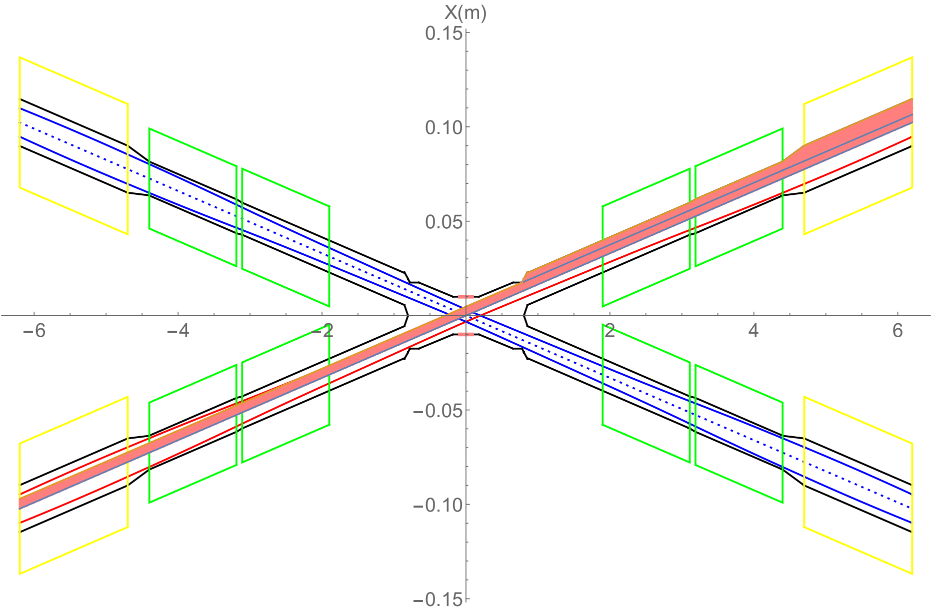
Injection BG

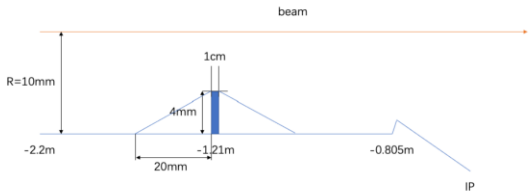
Background	Generation	Tracking	Detector Simu.
Synchrotron Radiation	BDSim/Geant4	BDSim/Geant4	CEPCSW/FLUKA
Beamstrahlung/Pair Production	Guinea-Pig++	SAD	
Beam-Thermal Photon	PyBTH[Ref]		
Beam-Gas Bremsstrahlung	PyBGB[Ref]		
Beam-Gas Coulomb	BGC in SAD		
Radiative Bhabha	BBBREM		
Touschek	TSC in SAD		

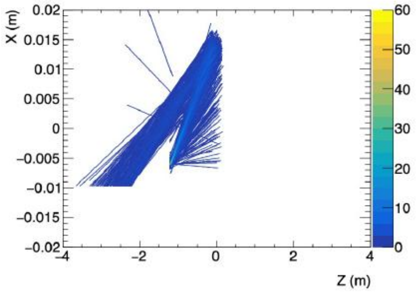
- One Beam Simulated
- Simulate each background separately
- Whole-Ring generation for single beam BGs
- Multi-turn tracking(200 turns)
  - Using built-in LOSSMAP
  - SR emitting/RF on
  - Radtaper on
  - No detector solenoid yet

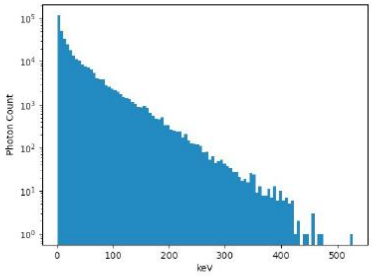
SR BG & Mitigation

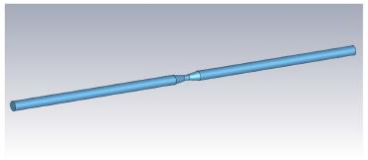
- The central beam pipe was carefully designed to avoid the direct hitting of the SR photons
- The masks are implemented to further mitigate the secondaries, the design is still on going.
  - Several ways has been attempted, including the shrinking of the incoming beam pipe and different position/material/design of the mask.

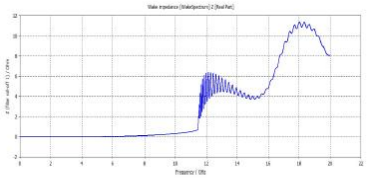










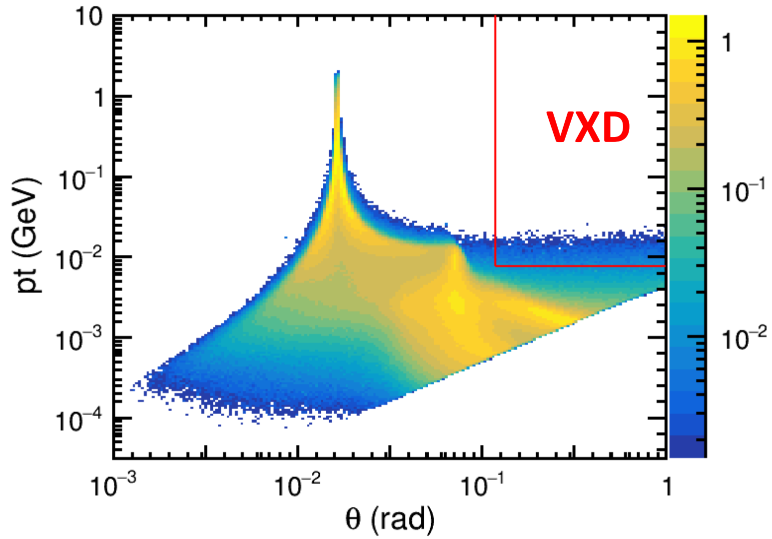


Methods	photon number of hitting on Be(N)
1.21-mask-Cu	1736.0
1.21-mask-W	1698.0
2.2-mask-Cu	1147.0
cons-no mask-Cu	257364.0
cons-no mask-W	148030.0
1.21-mask-Cu-5μmAu	216.0
nomask	39400.0

Pair Production(Beamstrahlung)

- Luminosity related backgrounds
- One of the dominant backgrounds at the CEPC, may lead to two different impacts:
  - The impacts on detector, caused by the electrons/positrons produced by photons
  - The impacts on accelerator components outside of the IR, caused by the photons directly.
- Hard to mitigate

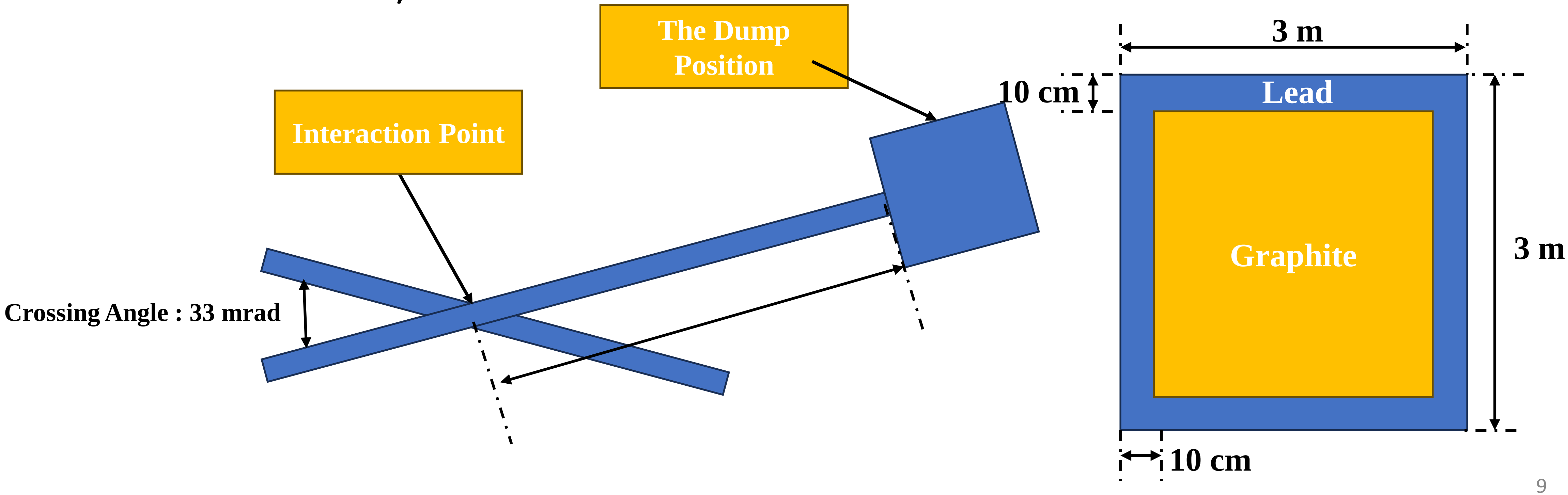
Parameter	Symbol	ILC-500	CLIC-380	CEPC-Z	FCC-Z	CEPC-W	FCC-W	CEPC-Higgs	FCC-Higgs	CEPC-top	FCC-top
Energy	E[GeV]	250	190	45.5	45.5	80	80	120	120	180	182.5
Particles per bunch	N[1e10]	3.7	2	14	24.3	13.5	29.1	13	20.4	20	23.7
Bunch Number				11934	10000	1297	880	268	248	35	40
Bunch Length	sigma_z [mm]	0.3	0.07	8.7	14.5	4.9	8.01	4.1	6.0	2.9	2.75
Collision Beam Size	sigma_x,y [um/nm]	0.474/5.9	0.149/2.9	6/35	8/34	13/42	21/66	14/36	14/36	39/113	39/69
Emittance	epsilon_x,y [nm/pm]	1e4/3.5e4	0.95e3/3e4	0.27/1.4	0.71/1.42	0.87/1.7	2.17/4.34	0.64/1.3	0.64/1.29	1.4/4.7	1.49/2.98
Betafunction	beta_x,y [m/mm]	0.011/0.48	0.0082/0.1	0.13/0.9	0.1/0.8	0.21/1	0.2/1	0.3/1	0.3/1	1.04/2.7	1/1.6
Factor	[1e-4]	612.7	6304.6	2.14	1.7	3.0	2.4	4.8	5.2	5.6	7.10
n_gamma		1.9	4.34	1.0	1.36	0.45	0.59	0.4	0.64	0.22	0.26
Relative loss per particle	%/BX	19.3		0.0041	0.0092	0.0067	0.0072	0.0096	0.0161	0.0062	0.0093



Mode	Higgs	Z(10MW)
Pairs/BX	~2200	~850

Beamstrahlung – Photon Dump

- We have completed the preliminary study on the photon dump and have already developed a reference design for it.
  - The extraction line and the modification of the magnets have not yet been incorporated into the design. The whole system design is on going.
  - The ambient equivalent dose constraint has been met, with a value of less than 5.5 mSv/h.

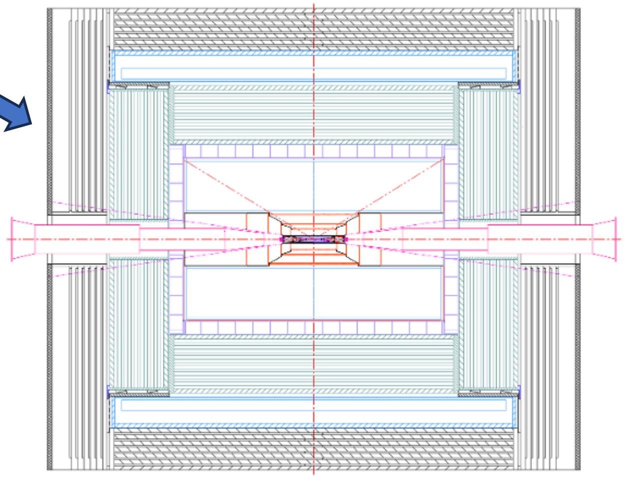


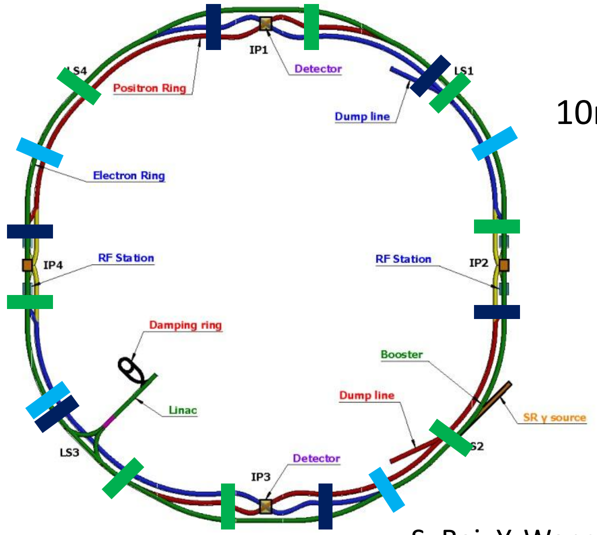
Mitigation of the Backgrounds

- Collimators were implemented to reduce IR loss caused by single beam.
  - 19 sets of collimators dedicated design for MDI
  - 12 sets of collimators were installed for passive machine protection and will also contribute to mitigating beam background.
- Collimator design Requirements:
  - Beam stay clear region: 18 σ_x+3mm, 22 σ_y+3mm
  - Impedance requirement: slope angle of collimator < 0.1
- With the implementation of collimators, multi-turn beamstrahlung and radiative Bhabha loss particles have been effectively shielded outside the interaction region.
- Shielding has been implemented at both ends of the yoke using the 10 cm of paraffin, and also 10mm W outside of the LumiCal-LYSO. The shell of cryo-module also used as shielding.

Q. Ji

10cm Paraffin



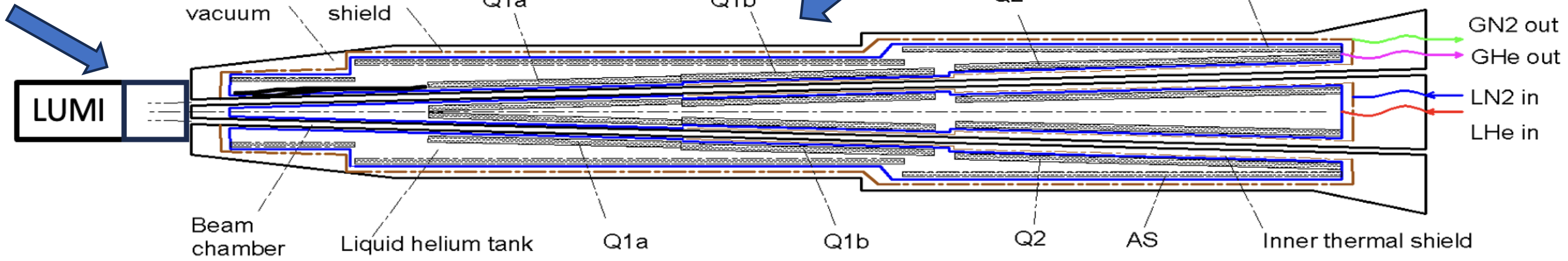


S. Bai, Y. Wang, X. Cui

15mm Stainless Steel Shell and Shielding

Y.Zhu, X.Zhang, X.Yang

10mm Tungsten



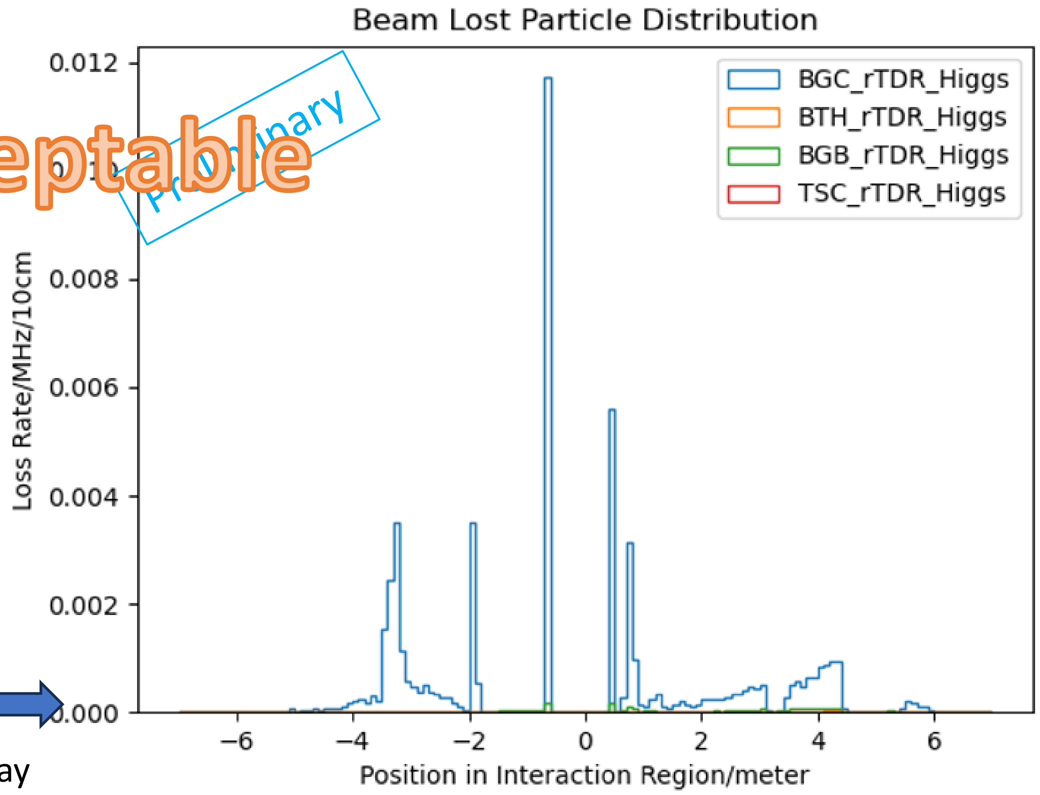
Loss Distribution

- Errors implemented
  - High order error for magnets
  - Beam-beam effect
- Detector Solenoid not yet considered in multi-turn tracking

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

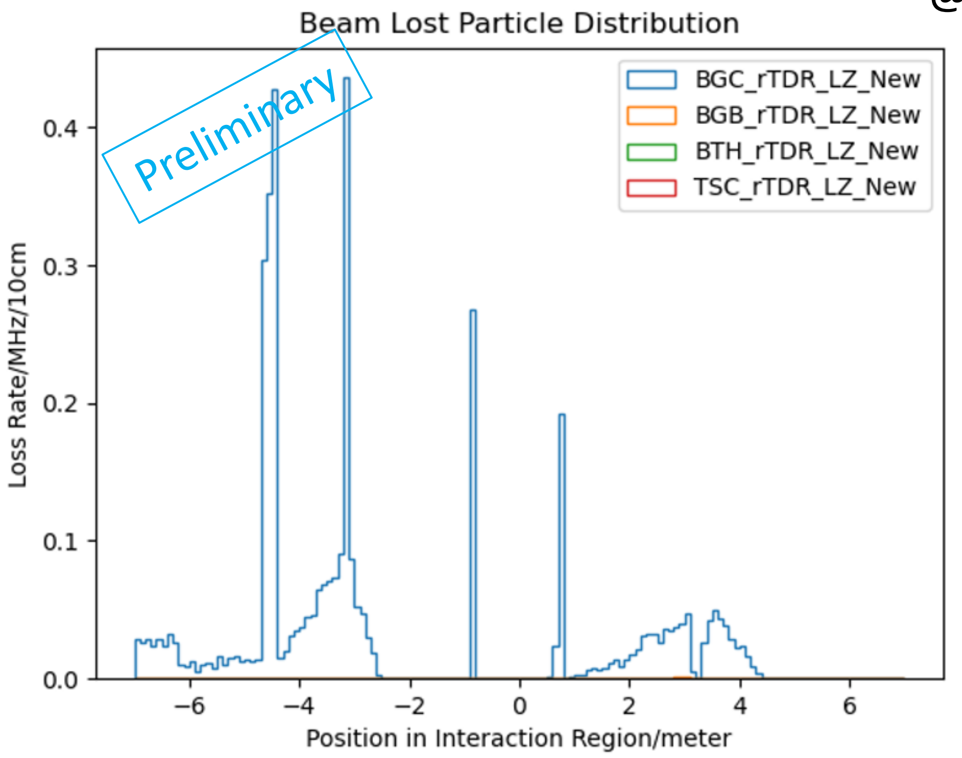
@Higgs

Acceptable



Beam Way

@Low-Lumi-Z



Estimation on Impacts in the IR

- Noise on Detector(Backgrounds)
  - Occupancy
  - Estimating using the same tool with Physics simulation
- Radiation Environment(Backgrounds + Signal)
  - Radiation Damage of the Material(Detector, Accelerator, Electronics, etc…)
    - Estimating using the same tool with physics simulation including the dose calculation
    - Or FLUKA
  - Effects of Radiation on Human Health and the Environment
    - Estimating using the same tool with physics simulation including the dose calculation
    - Or FLUKA
- The detector simulation for Reference Detector is ongoing.

BG Level at Higgs/Z with mitigation

- We have obtained a preliminary estimate of the beam-induced background levels in all 3 mode
  - The VXD results taken the SR into account.

Table 3.13: The BG Level with Shielding

Sub-Detectors	Ave. Hit Rate			Max. Hit Rate			Max. Occupancy Per BX(%)		
	Higgs	Low-Lumi-Z	High-Lumi-Z	Higgs	Low-Lumi-Z	High-Lumi-Z	Higgs	Low-Lumi-Z	High-Lumi-Z
VXD(MHz/cm^2)	2.2	8.8	27.0	2.6	17	53	0.002	0.002	0.002
ITK-B/E(kHz/cm^2)	0.63/2.8	1.0/4.0	3.8/14	1.0/13	2.8/20	15/72	3.8e-5	7.6e-6	6.2e-6
TPC(kHz/cm^2)	3.4	3.7	-	11	13	-	0.066	0.078	-
OTK-B/E(kHz/cm^2)	0.68/0.93	1.2/1.6	7.6/8.9	1.1/4.1	1.9/6.6	10/21	3.7e-3/3.7e-2	7.8e-6/6.2e-3	8.0e-6/6.6e-5
ECal-B/E(MHz/bar)	0.012/0.045	0.011/0.046	0.034/0.144	0.43/2.9	0.28/4.2	0.82/13	0.54/2.3	0.14/0.57	0.15/0.48
HCal-B/E(kHz/gs cell)	0.17/5.3	0.70/5.1	1.9/16	5.2/2.2e2	8.7/1.2e2	26/4.1e2	4.6e-6/0.013	1.8e-6/2.5e-5	9.0e-7/2.6e-5
Muon-E(Hz/cm^2)	1.4	1.8	5.9	2.9	10	30	0.20	0.08	0.09

Radiation Map @ Higgs (Pairs only)

- The radiation map has been simulated @Higgs using FLUKA

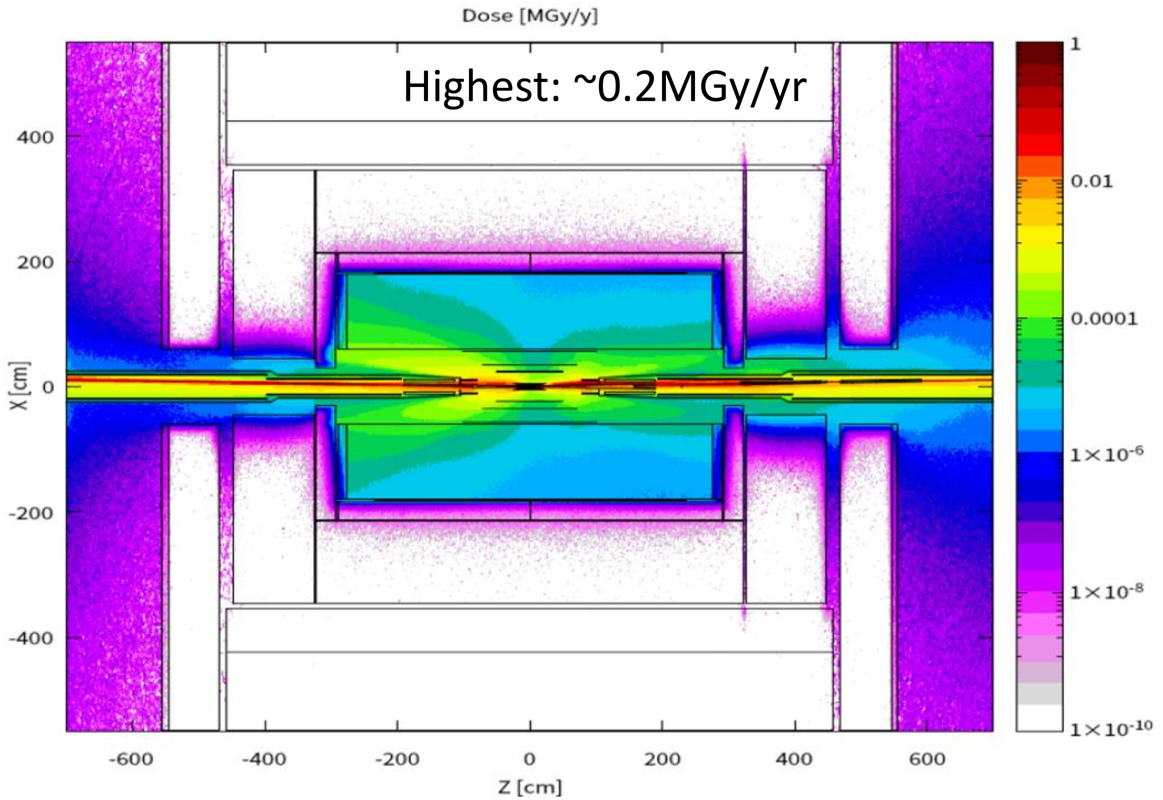


Figure 3.21: The TID distribution caused by Pair Production at the MDI Region, the higest TID is roughly 0.2MGy per year.

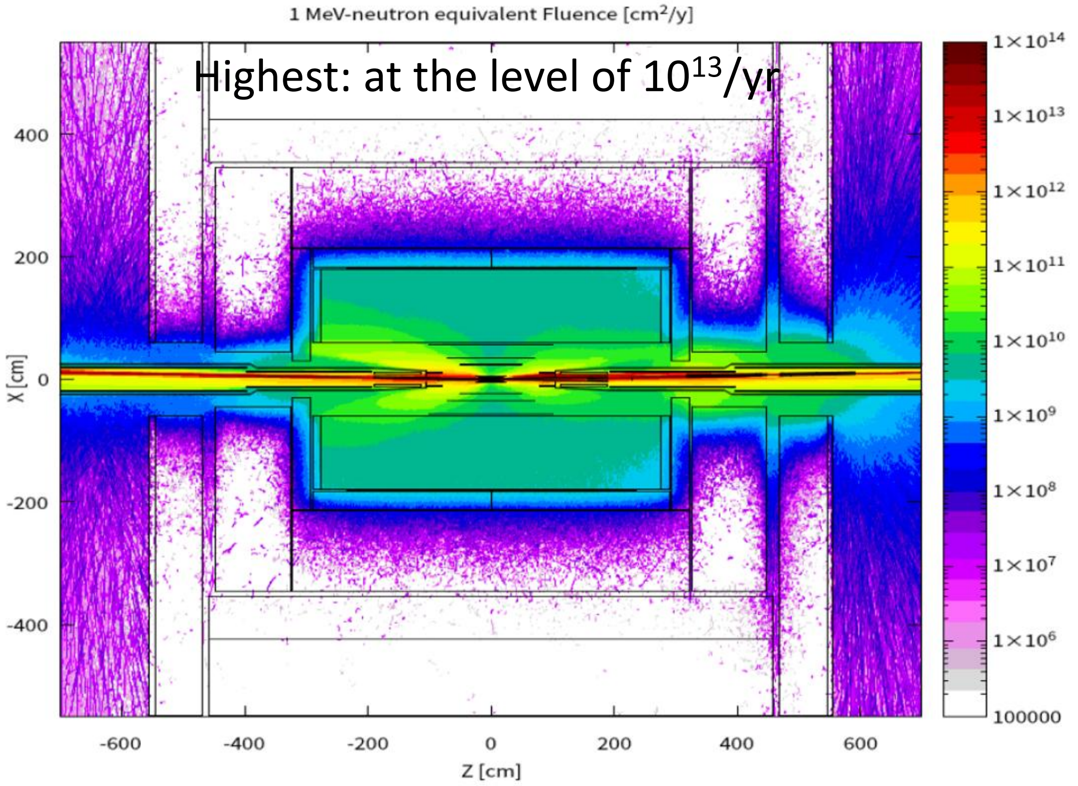


Figure 3.22: The NIEL distribution caused by Pair Production at the MDI Region, the highest number of the 1 MeV silicon equivalent fluence is at the level of 10^{13} per year.

Possible Collaboration

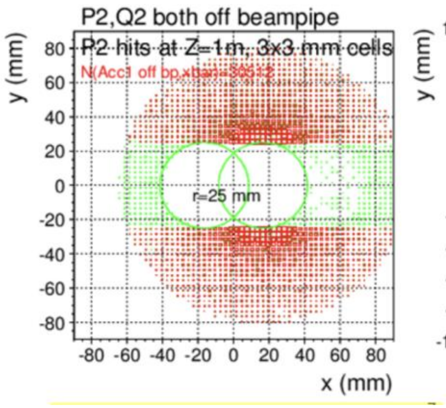
- Generation/Generator of the Beam Induced Background
- Physics Impact Estimation
- Radiation Level Estimation
- And much more

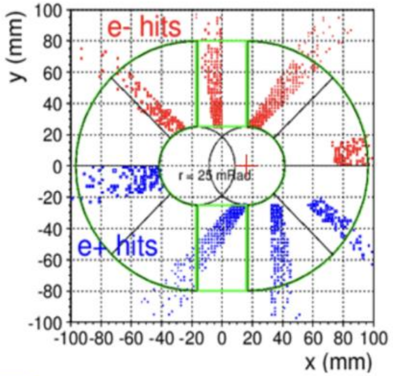
Thank You

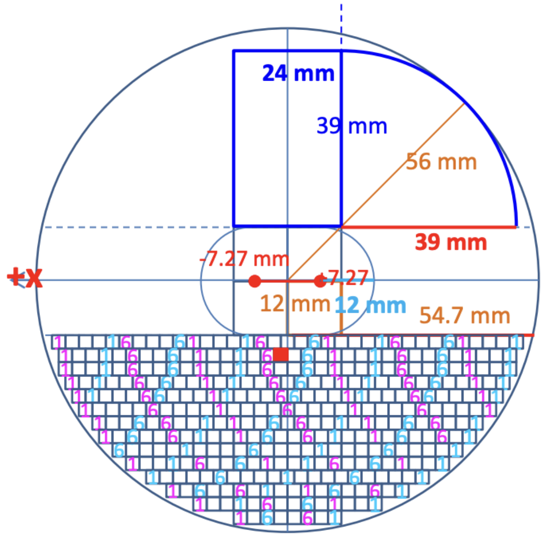
Backup

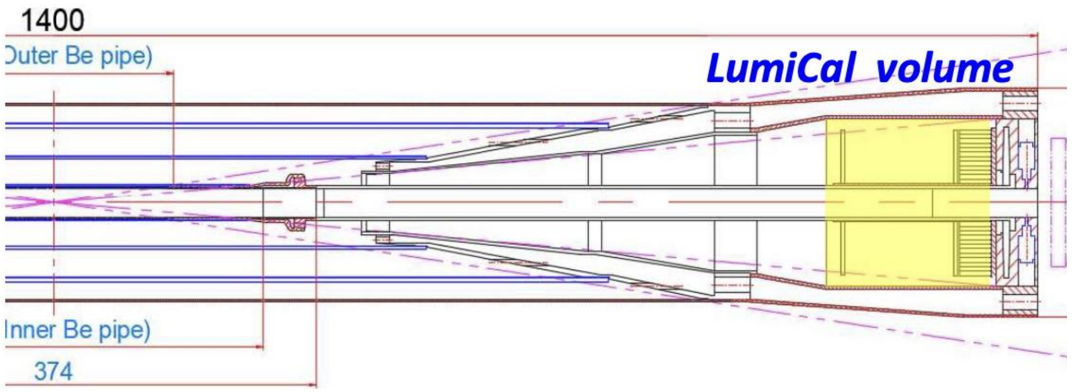
Design of the LumiCal

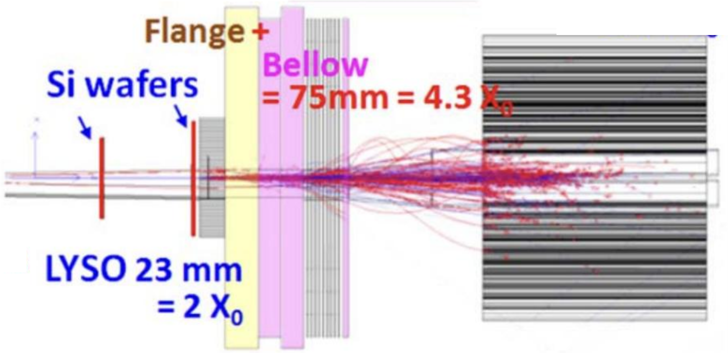
- The Latest LumiCal Design:
  - Two parts, one before Flange, and one after
  - LumiCal before flange:
    - 560~700mm
    - Two Si-wafers, $2X_0$ LYSO
  - LumiCal after bellow:
    - 800~950mm
    - $\sim 13X_0$ LYSO

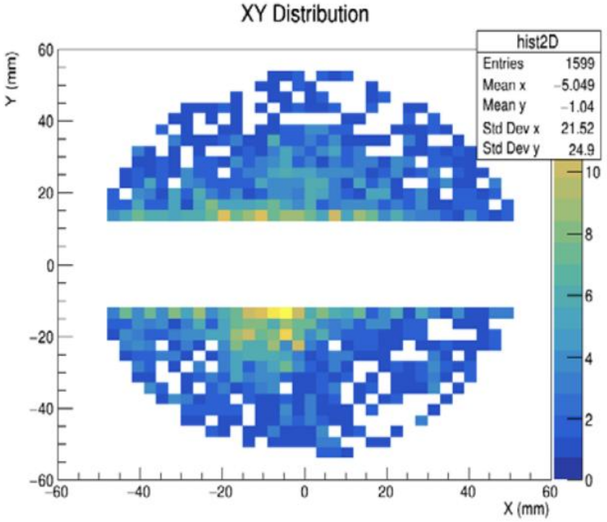




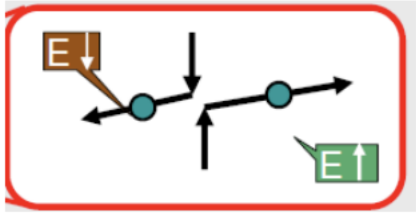








Touschek scattering



- Intra-bunch Coulomb scattering
- Beam particles
- Rate $\propto (beam\ size)^{-1}, E^{-3}$
- Lifetime estimation:

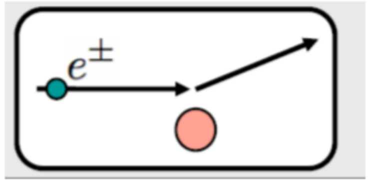
$$\frac{1}{\tau} = \frac{N r_e^2 c}{8\pi\sigma_x\sigma_y\sigma_z\gamma^2}\left(\frac{1}{\eta^3}\right)D(\xi)$$

- Should not have huge impact on High Energy colliders like CEPC
  - Also exists on linear colliders

Machine Name	Touschek Lifetime
BEPCII	5.21h
SuperKEKB – HER – Phase 1	~ 3.1h
SuperKEKB – LER - Phase 1	~ 3.3h
LEP 1	
CEPC – Higgs	119h

Beam Gas Scattering - elastic

Coulomb



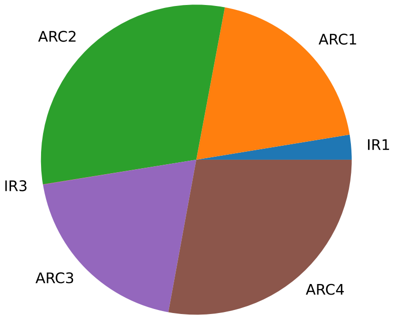
- Coulomb scattering with residual gas
- Beam Particles(with orbit changing)
- Rate $\propto P, Z,\ T^{-1}, E^{-1}, R^{-2}$, related to beta function

$$\sigma_{matt} = \frac{4\pi Z^2 r_e^2}{\gamma^2}\left(\frac{1}{\theta_{min}^2 + \theta_1^2}\right) = \frac{4\pi Z^2 r_e^2}{\gamma} \cdot \frac{192\beta_s\beta_{max}}{192\gamma R^2 + \beta_s\beta_{max}Z^{2/3}}$$

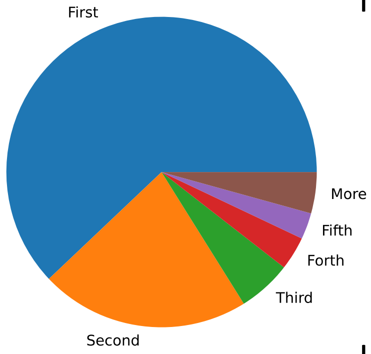
$$\frac{1}{\tau} = \sigma\rho_{gas}c = \sigma c\frac{P}{k_B T}$$

- Should also not have huge impacts on high energy colliders like CEPC, but decay slope slowly than touschek.
  - Also exists at linear colliders
- The small size of pipe radius will cause higher rates.

Machine Name	Beam Gas Coulomb Lifetime
BEPCII	56.1h
SuperKEKB – HER – Phase 1	~ 5.4h
SuperKEKB – LER – Phase 1	~ 14.4h
LEP 1	430h
CEPC – Higgs	27.99h



Loss Pos @ CEPC-Higgs
IR: 2.6%



Loss turn @ CEPC-Higgs

Beam Gas Scattering - inelastic

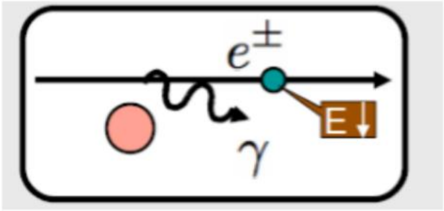
- Bremsstrahlung between beam particles and residual gas
- Beam particles(mainly) and photons
- Rate $\propto P,\ \ T^{-1}$, related to Z

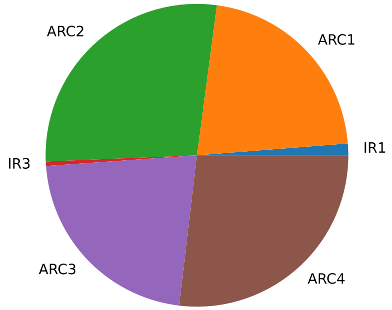
$$\sigma_{brem} = 4\alpha r_e^2 [\frac{4}{3}\left(ln\frac{1}{\eta} - \frac{5}{8}\right)F(Z) + \frac{1}{9}Z(Z+1)(ln\frac{1}{\eta} - 1)] \qquad \frac{1}{\tau} = \sigma\rho_{gas}c = \sigma c\frac{P}{k_B T}$$

- Not depends on E, therefore, would be significant at high energy colliders like CEPC
  - Also exists at linear colliders

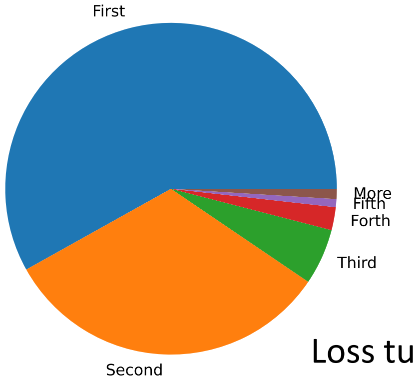
Machine Name	Beam Gas Brems Lifetime
BEPCII	50.7h
SuperKEKB – HER - Phase 1	~ 3.2h
SuperKEKB – LER – Phase 1	~ 3.9h
LEP 1	
CEPC – Higgs	248.90h

Brems





Loss Pos@ CEPC-Higgs
IR: 1.6%



Loss turn @ CEPC-Higgs

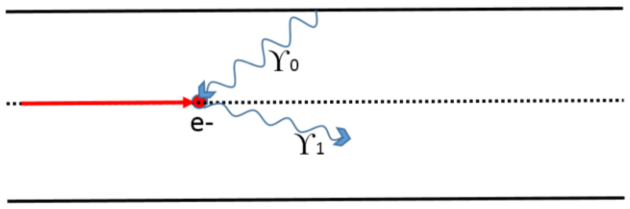
Beam Thermal Photon

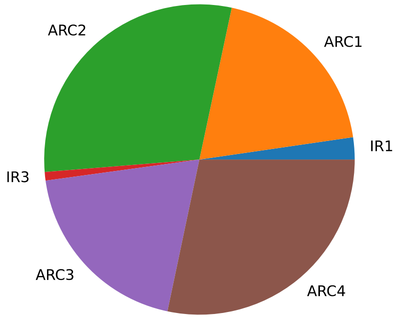
- Compton scattering between beam particles and thermal photons
- Beam particles(mainly) and photons
- Rate ∝ $T^3, f; f\ related\ to\ \eta^{-1}, E^{-1}$

$$\frac{1}{\tau} = \rho_\gamma c \sigma_T f = 8\pi(\frac{kT}{hc})^3 \int_0^\infty \frac{x^2}{e^x - 1} dx \cdot c \cdot \frac{8\pi}{3} r_e^2 \cdot f$$

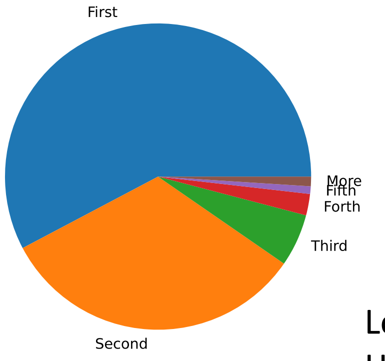
- Not depends on E(besides f), therefore would be significant at high energy colliders like CEPC
  - Also exists at linear colliders
  - For T=24℃, $\rho_\gamma = 5.329 \times 10^{14} m^{-3}$, <e>=0.07eV, $\rho_\gamma c \sigma_T$ is about 26.2h, f is the loss ratio which determined by experiment(or simulation)
  - The energy of E would be increased as γ^2, <e> is ~550 MeV@Z, 3.86 GeV@Higgs, 8.7 GeV@ttbar

	Higgs	Z	ttbar	W
f	0.51718	0.37238	0.5471725	0.47443
Beam Lifetime	50.66h	70.19h	47.88h	55.22h





Loss Pos@ CEPC-Higgs
IR: 3.1%



Loss turn @ CEPC-Higgs