Study Status of Beam Backgrounds at the CEPC

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On behalf of the CEPC MDI Working Group

The 2022 International Workshop of the CEPC

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Outline

- Introduction
- The new IR beam pipe design
- Beam Background Study
- Summary & Outlook

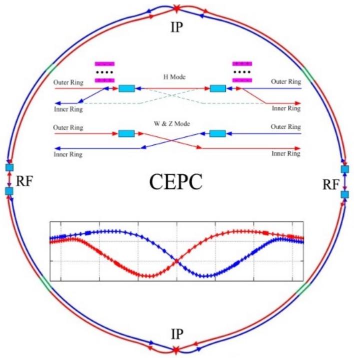
Introduction

- 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

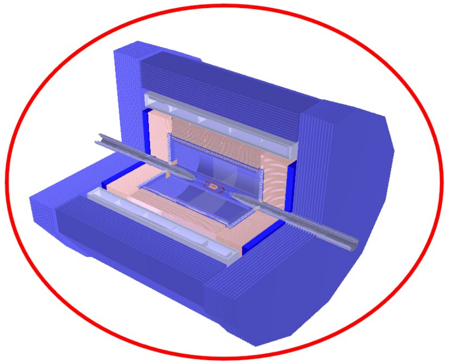
	ttbar	Higgs	W	Z
Number of Ips		2		
Circumference [km]		100.0		
SR power per beam [MW]		30		
Half crossing angle at IP [mrad]		16.5		
Bending radius [km]		10.7		
Energy [GeV]	180	120	80	45.5
Energy loss per turn [GeV]	9.1	1.8	0.357	0.037
Piwinski angle	1.21	5.94	6.08	24.68
Bunch number	35	249	1297	11951
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]
Beam size at IP (sigx/sigy) [um/nm]	39/113	15/36	[illegible]	[illegible]
Bunch length (SR/total) [mm]	2.2/2.9	[illegible]	[illegible]	2.5/8.7
Energy spread (SR/total) [%]	[illegible]	[illegible]	[illegible]	0.04/0.13
Energy acceptance (DA/RF) [%]	[illegible]	[illegible]	1.2/2.5	1.3/1.7
Beam-beam parameters (ksix/ksiy)	[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

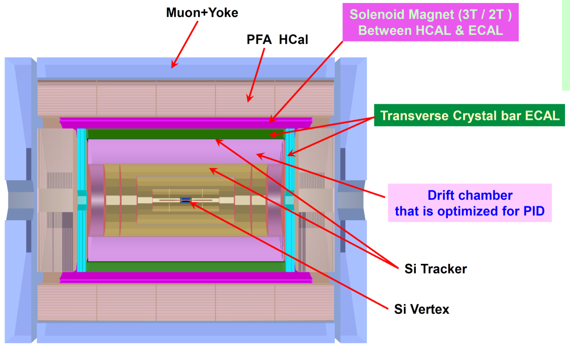
2021 Improved Design

67%⇑ 259%⇑



Particle Flow Approach
(ILD-like)





4th Detector concept

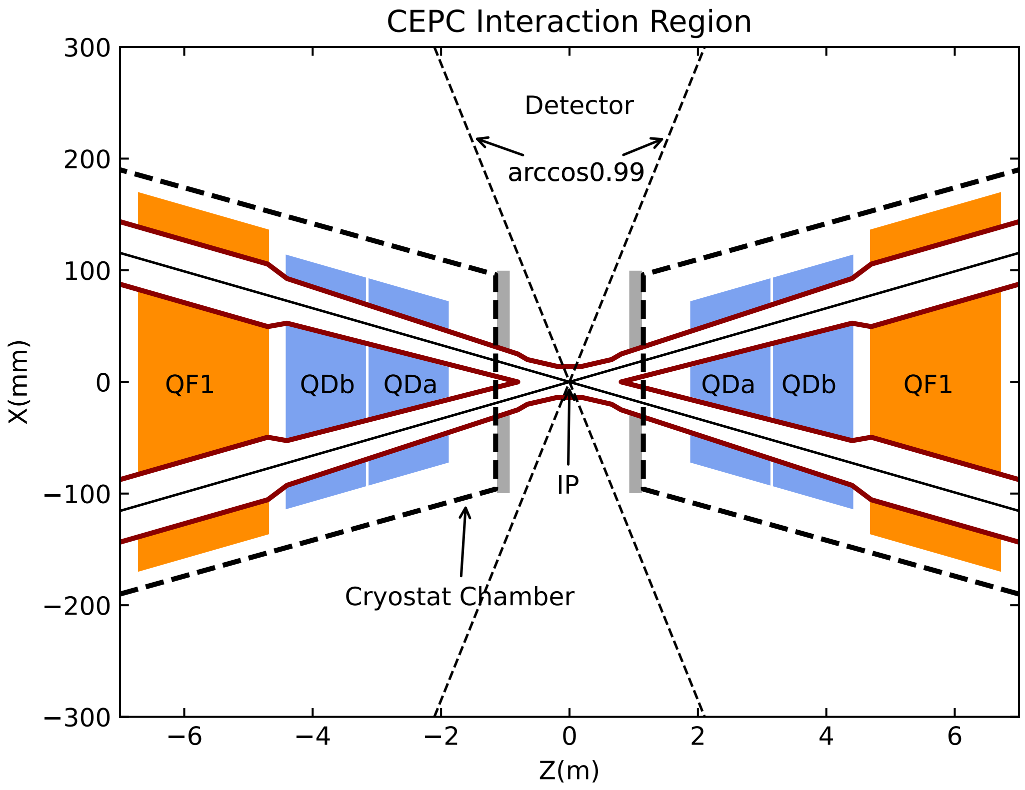
MDI Parameter Table

S. Bai

	range	Peak filed in coil	Central filed 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*	0~1.9m				1.9m								
Crossing angle	33mrad												
MDI length	±7m												
Detector requirement of accelerator components in opening angle	8.11˚												
QDa/QDb		3.2/2.8 T	141/84.7T/m		1.21m	15.2/17.9mm	62.71/105.28 mm	48mm	59mm	724.7/663.1keV	396.3/263keV	212.2/239.23 W	99.9/42.8 W
QF1		3.3T	94.8T/m		1.5m	24.14mm	155.11mm	56mm	69mm	675.2keV	499.4keV	472.9W	135.1W
Lumical	0.95~1.11m				0.16m			57mm	200mm				
Anti-solenoid before QD0		8.2T			1.1m			120mm	390mm				
Anti-solenoid QD0		3T			2.5m			120mm	390mm				
Anti-solenoid QF1		3T			1.5m			120mm	390mm				
Beryllium pipe					±120mm			28mm					
Last B upstream	64.97~153.5m			0.77mrad	88.5m					33.3keV			
First B downstream	44.4~102m			1.17mrad	57.6m					77.9keV			
Beampipe within QDa/QDb					1.21m							1.19/1.31W	
Beampipe within QF1					1.5m							2.39W	
Beampipe between QD0/QF1					0.3m							26.5W	

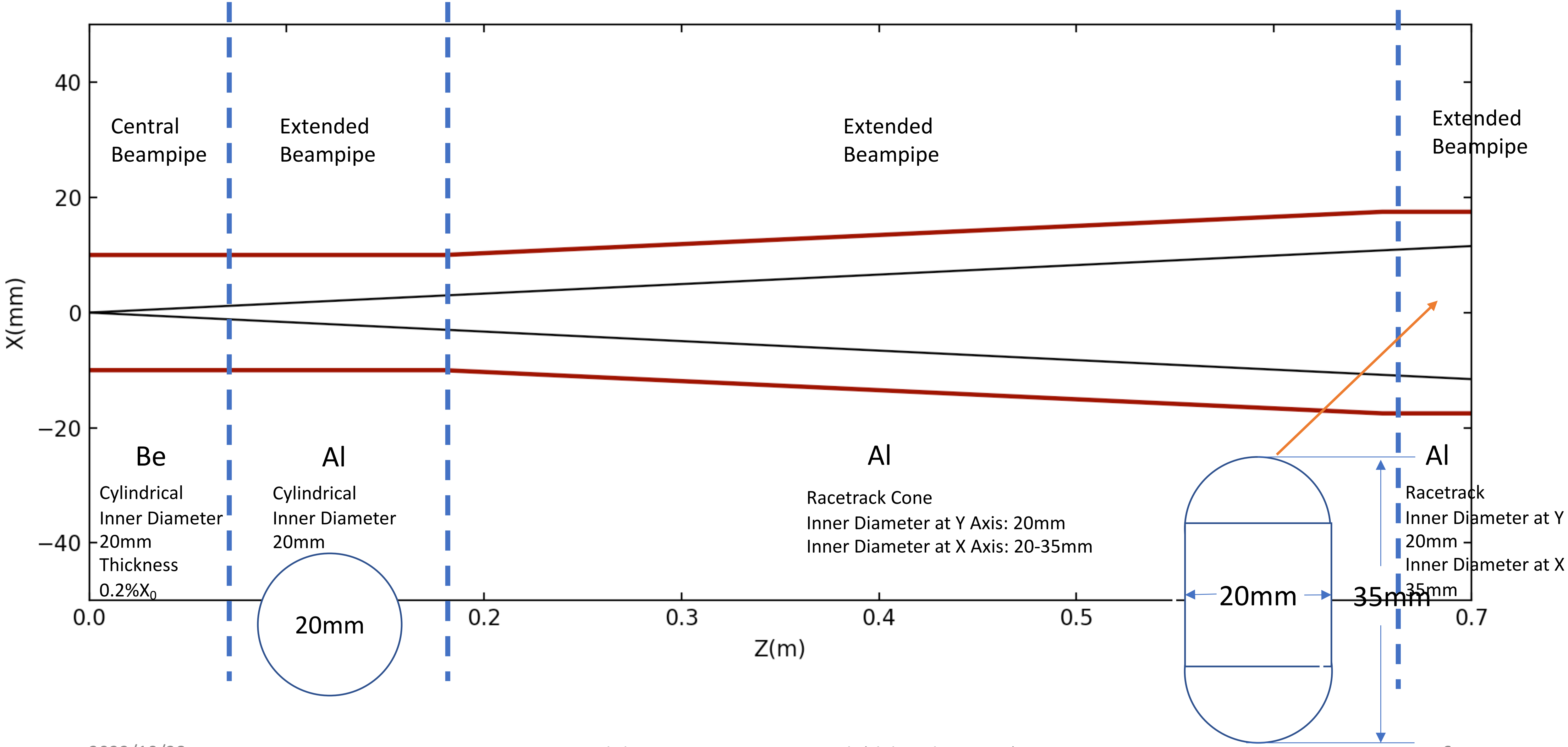
Updated IR

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



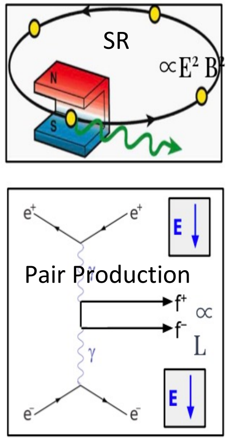
The length of Interaction Region is -7m~7m at TDR Phase

New Beampipe Design – Half Detector pipe

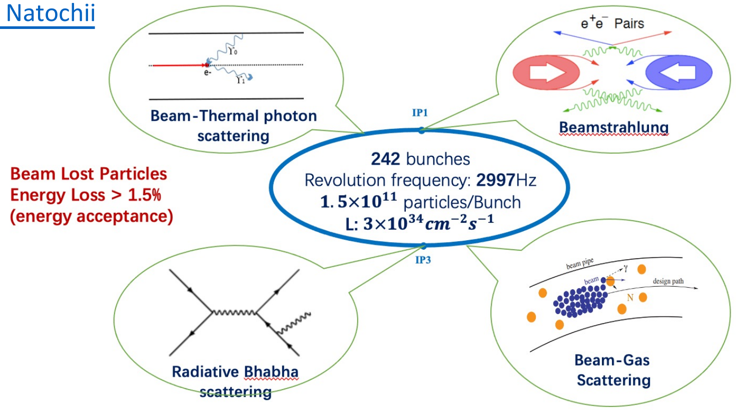


Background Estimation

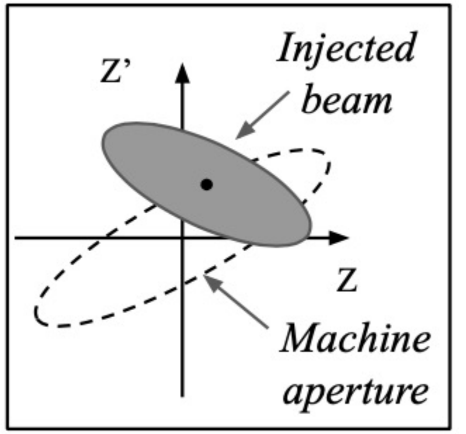
- Simulate each background separately
- Whole-Ring generation for single beam BGs
- Multi-turn tracking(50 turns)
  - Using built-in LOSSMAP
  - SR emitting/RF on
  - Radtaper on
  - No detector solenoid yet
- Errors implemented
  - High order error for magnets
  - Beam-beam effect
- 2 IR considered(sum)
- Plan to study the photon bkgs generated during all processes, both single beam and luminosity related.



A. Natochii



A. Natochii



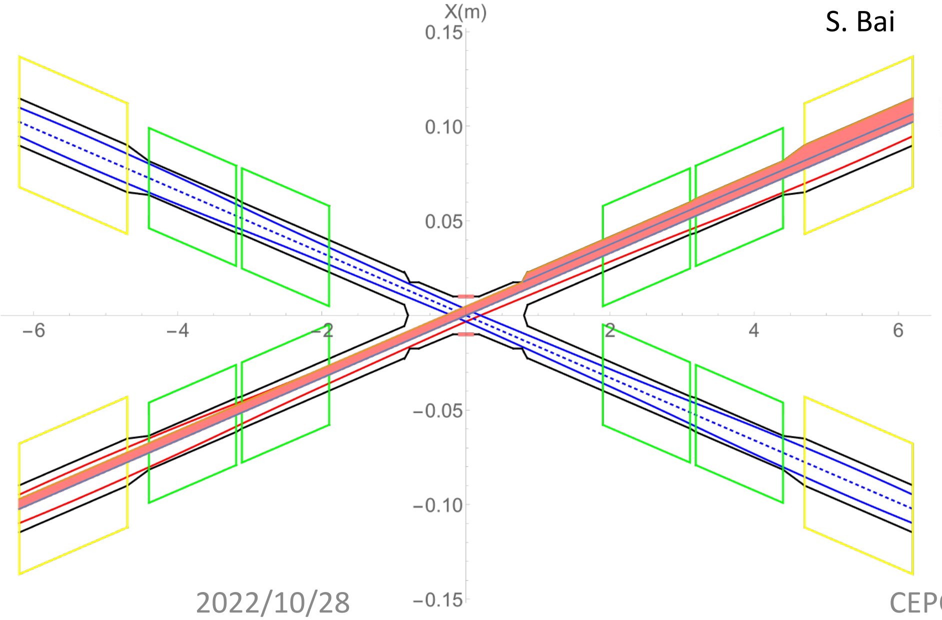
Photon BG | Beam Loss BG | Injection BG

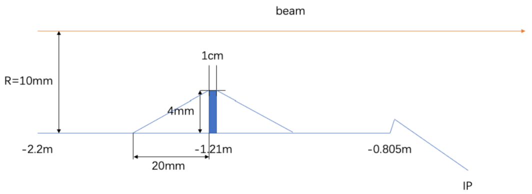
Background	Generation	Tracking	Detector Simu.
Synchrotron Radiation	BDSim	BDSim/Geant4	Mokka/CEPCSW
Beamstrahlung/Pair Production	Guinea-Pig++	SAD	
Beam-Thermal Photon	PyBTH[Ref]		
Beam-Gas Bremsstrahlung	PyBGB[Ref]		
Beam-Gas Coulomb	BGC in SAD		
Radiative Bhabha	BBBREM		

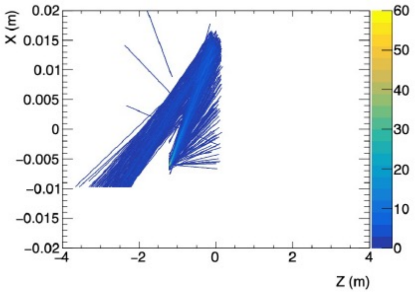
SR BG & Mitigation

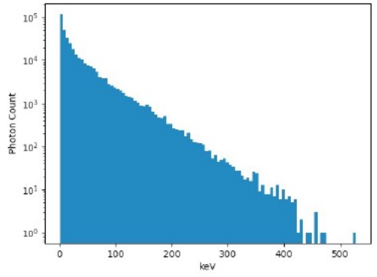
- The SR must be dealt with high priority when designing the circular machine. At the CEPC, there would be no SR photons hitting the central beam pipe directly in normal conditions
- However, some secondaries generated within QD would hit the detector beampipe, even the beryllium part. Therefore, the 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.

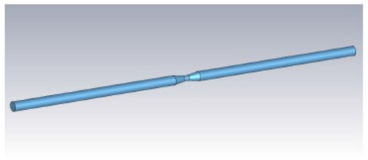
S. Bai

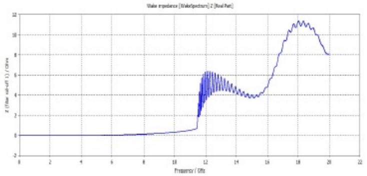












Y. Sun

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

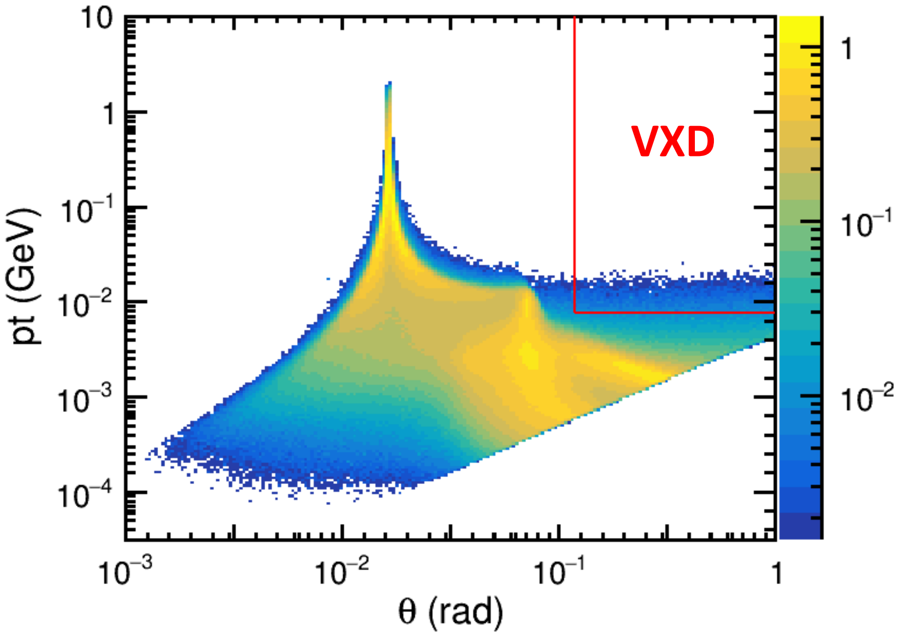
- Pair Production(Beamstrahlung) is one of the dominant background process at the CEPC.

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
Power Deposited by photon	P [W]										
SR Relative loss	%/turn							1.3			

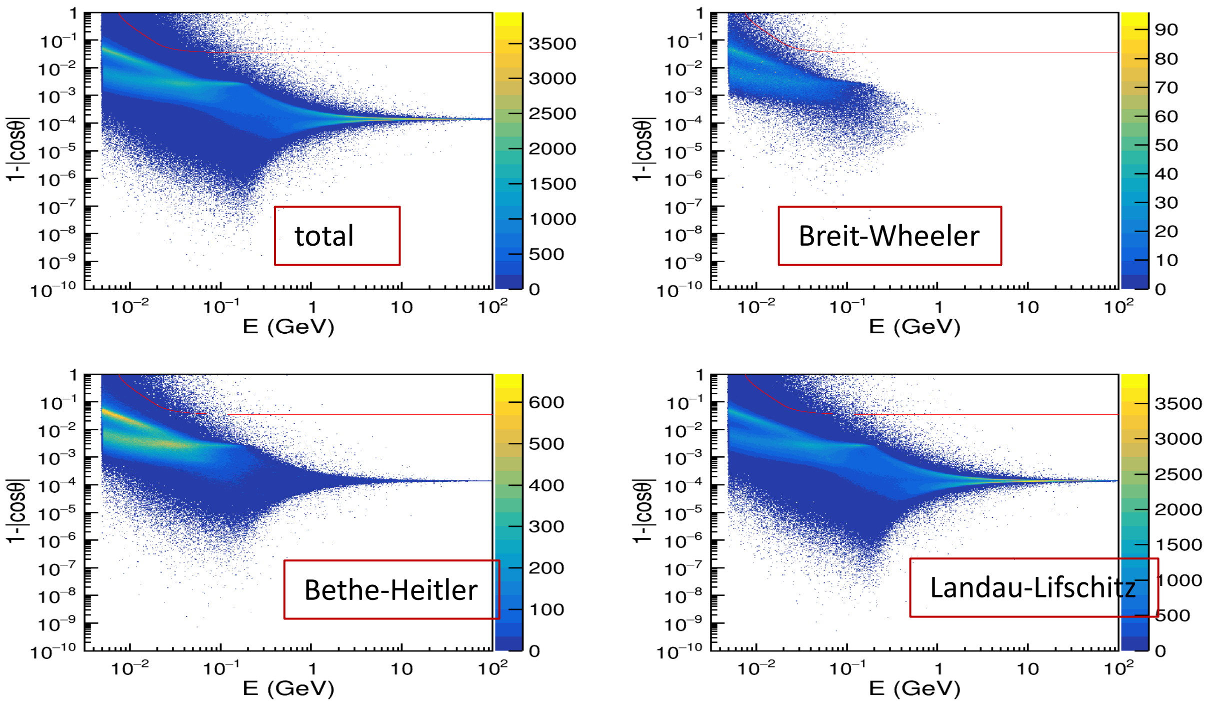
Pair Production

- Pair Production(Beamstrahlung) 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.

W. Xu



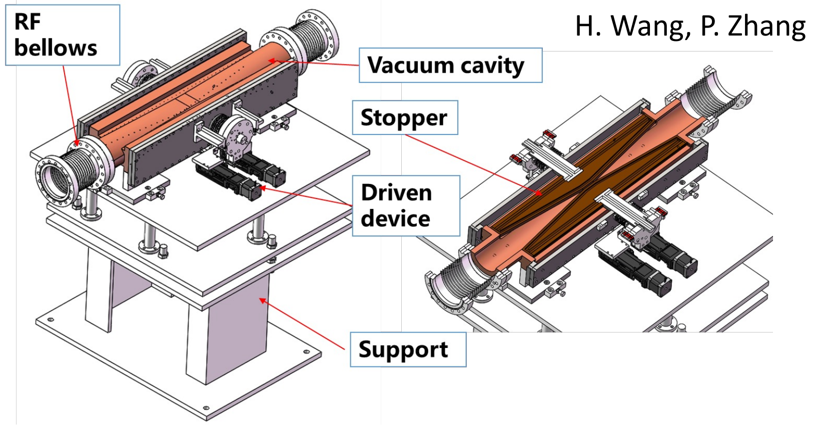
W. Xu



Mitigation of the BG - Collimator

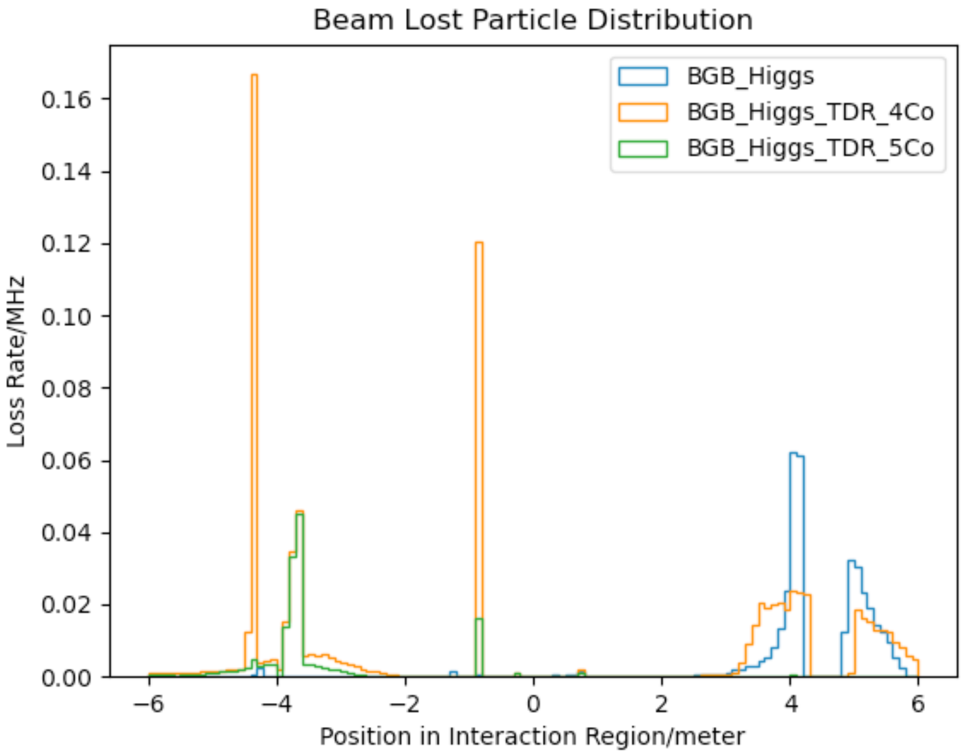
- Beam stay clear region: 18 σ_x+3mm, 22 σ_y+3mm
- Impedance requirement: slope angle of collimator < 0.1
- 4 sets of collimators were implemented per IP per Ring(16 in total)
  - 2 sets are horizontal(4mm radius), 2 sets are vertical(3mm radius).
- One more upstream horizontal collimator were implemented to mitigate the Beam-Gas background

H. Wang, P. Zhang



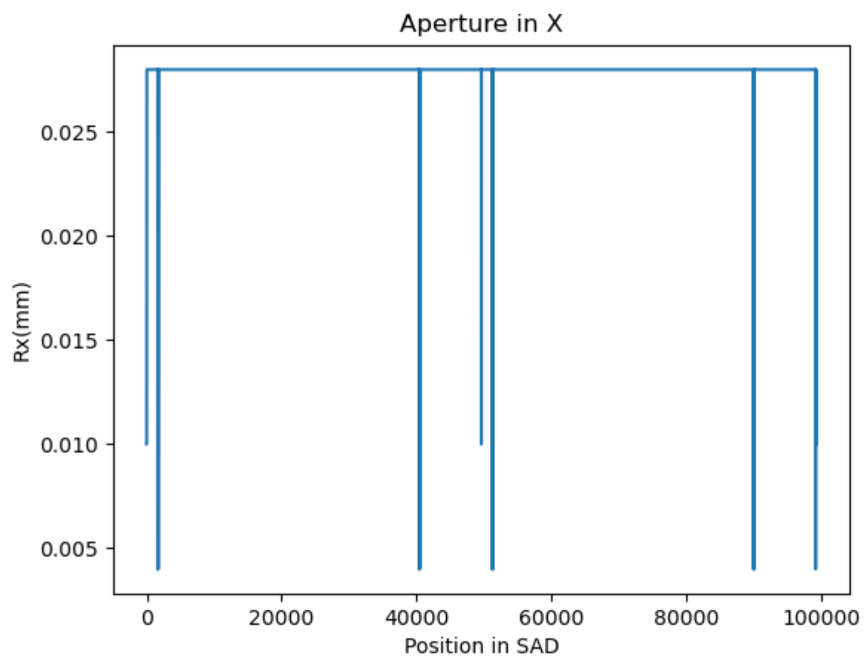
S. Bai

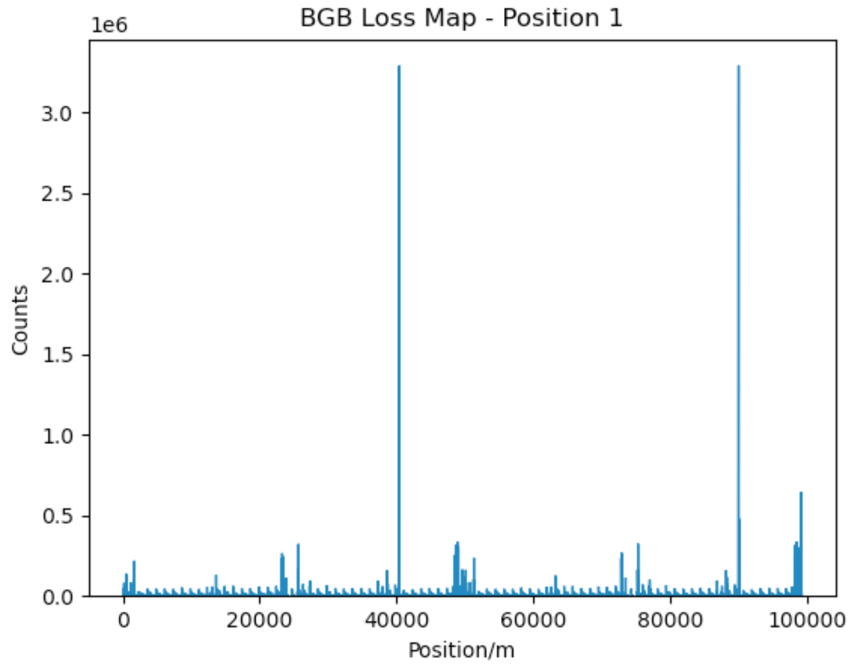
name	Position	Distance to IP/m	Beta function/m	Horizontal Dispersion /m	Phase	BSC/2/m	Range of half width allowed/mm
APTX1	D1I.785	44611	20.7	0.12	164.00	0.006	1~6
APTX2	D1I.788	44680	20.7	0.12	164.25	0.006	1~6
APTY1	D1I.791	44745	105.37	0.12	165.18	0.0036	0.156~3.6
APTY2	D1I.794	44817	113.83	0.12	165.43	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	DMBV01IRU0	56.3	196.59	0	362.86	0.01178	2.9~11.78



Aperture Model – With Collimator

- The diameter of the beampipe in all regions except the IR and collimator is 56mm, with the length of the components itself.
- The drift chambers and dipoles in the IR and 200m before the IR are sliced into 10cm, with aperture set properly.
  - Since the beam-gas coulomb scattering has not been well studied yet, only X apertures is presented.

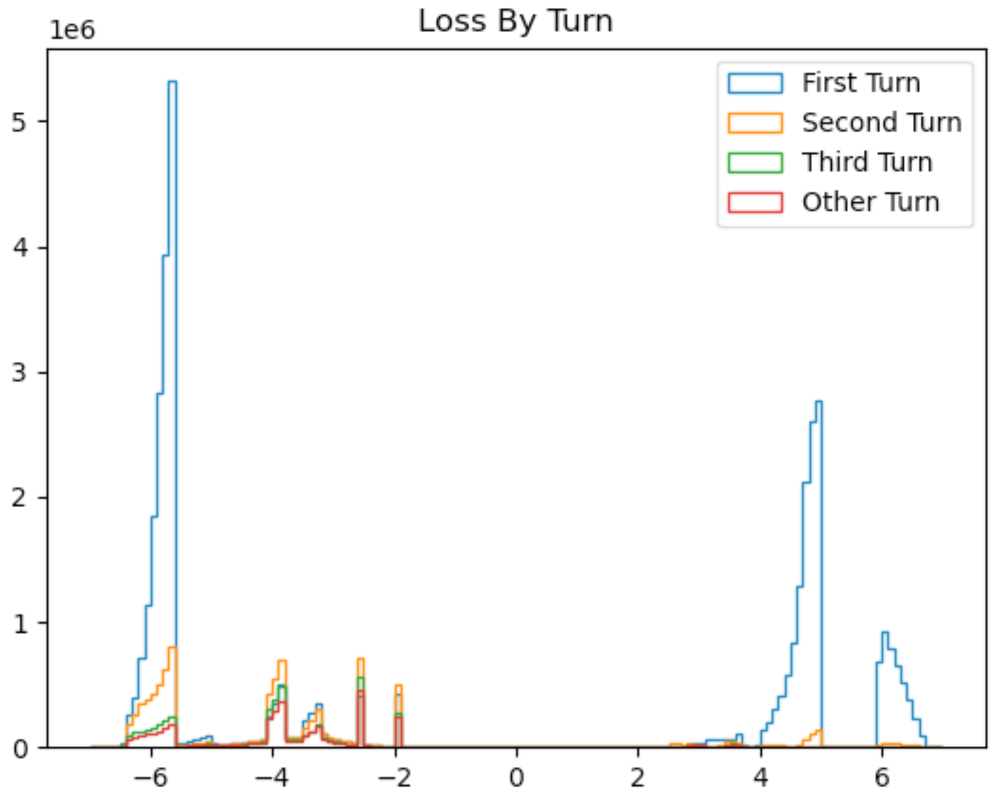




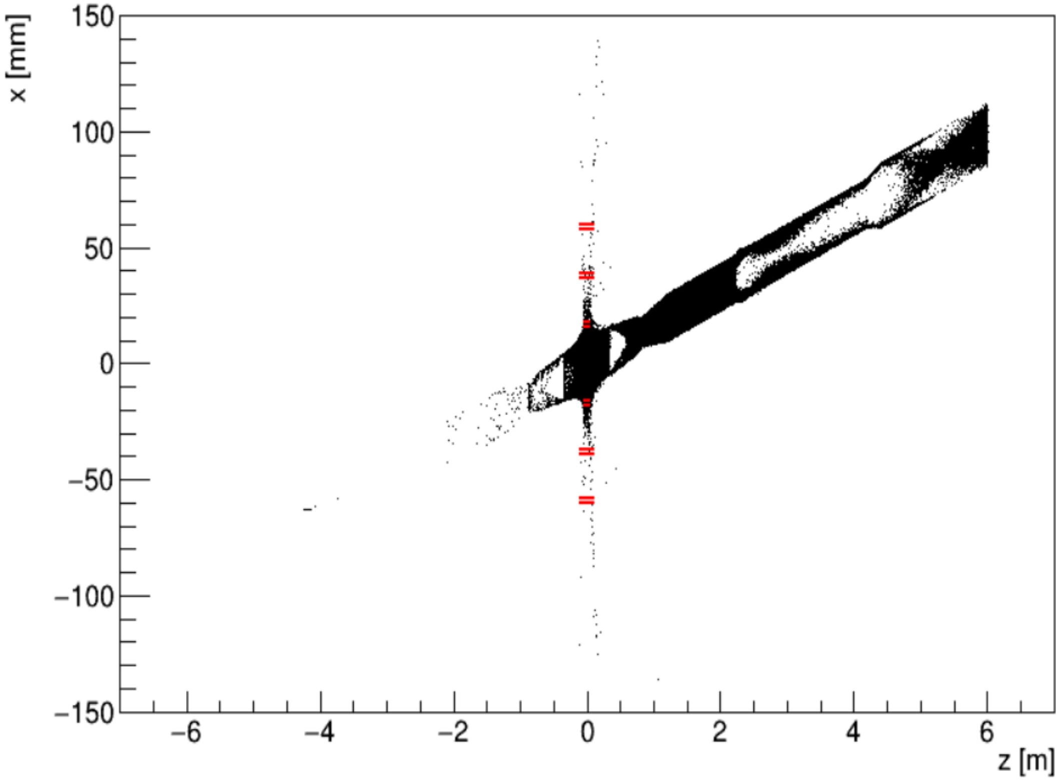
Loss Distribution – With Collimators

- The loss in first turn dominants.

BGB

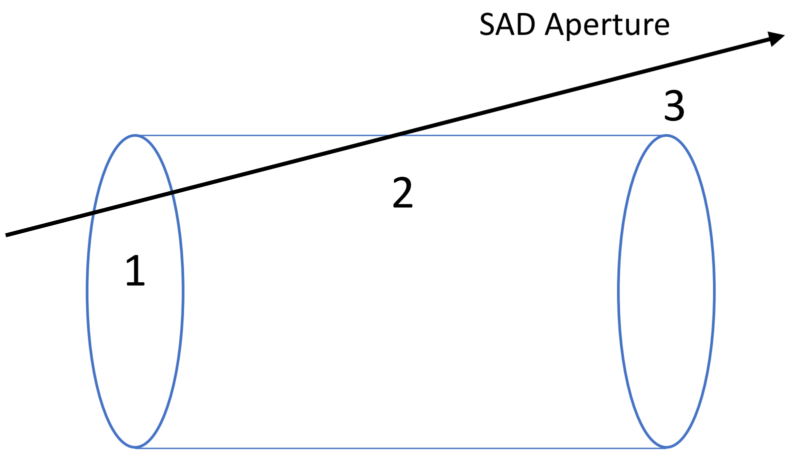


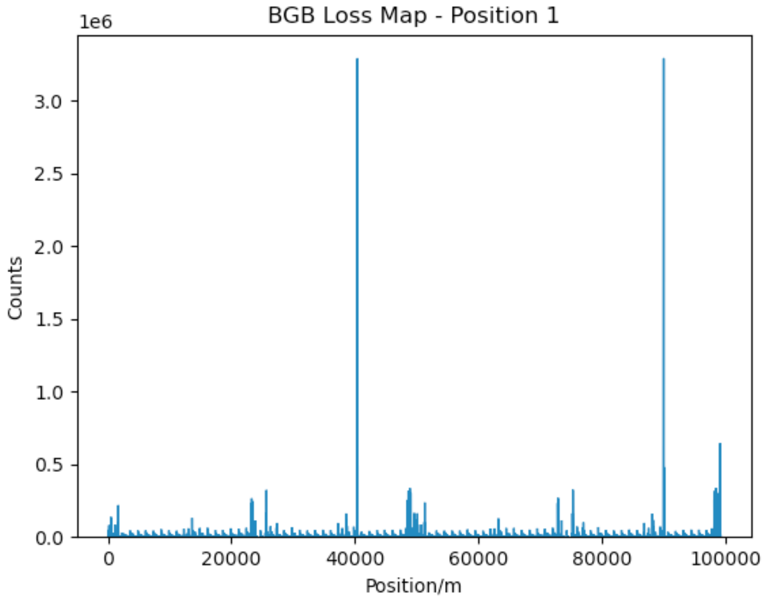
RBB

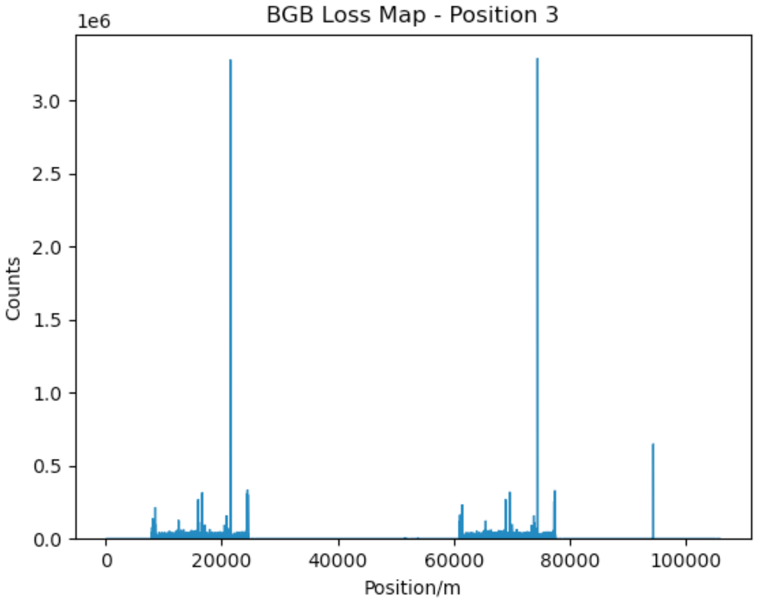


Particle Position Optimization

- We learnt than the position outputted by SAD might not be true.
  - In our previous study, we used the position "1" as the loss position
  - To do so, we have to perform the simulation twice.
  - However, SAD is a monte carlo simulation program. When the twice simulation performed, the position "1" might be changed.
  - Therefore, the position "3" should be used with changing the position of X/Y.

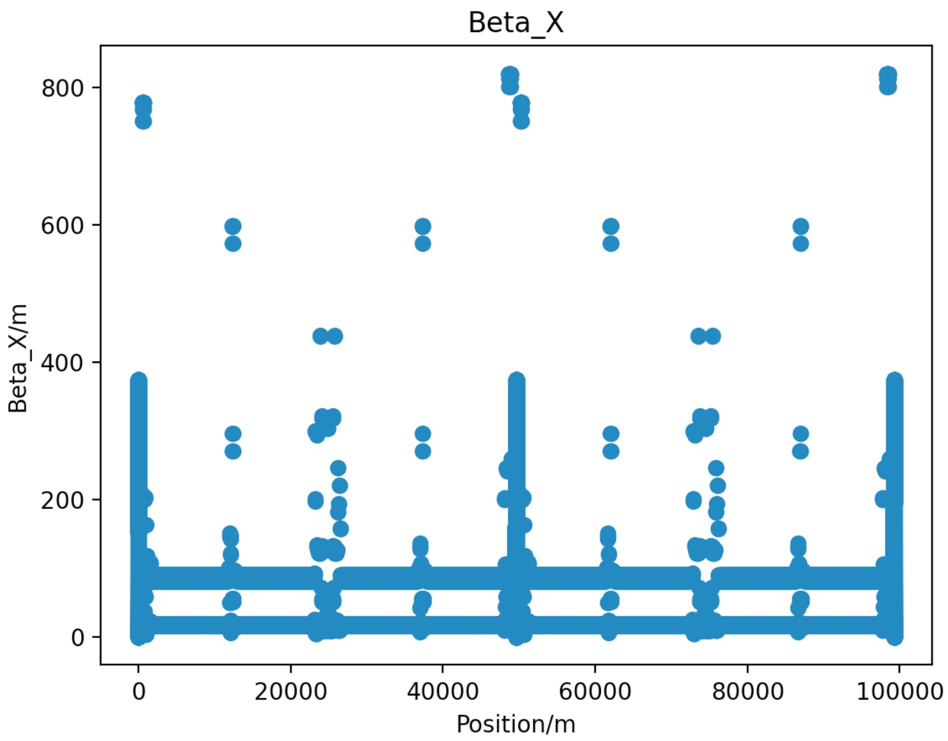


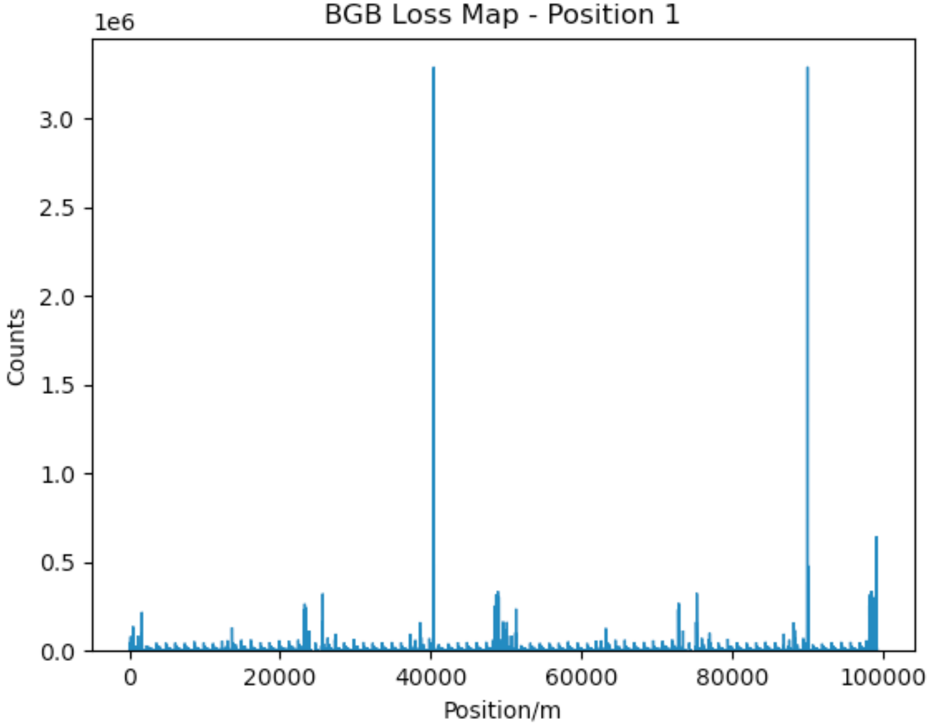




Where these peaks come from?

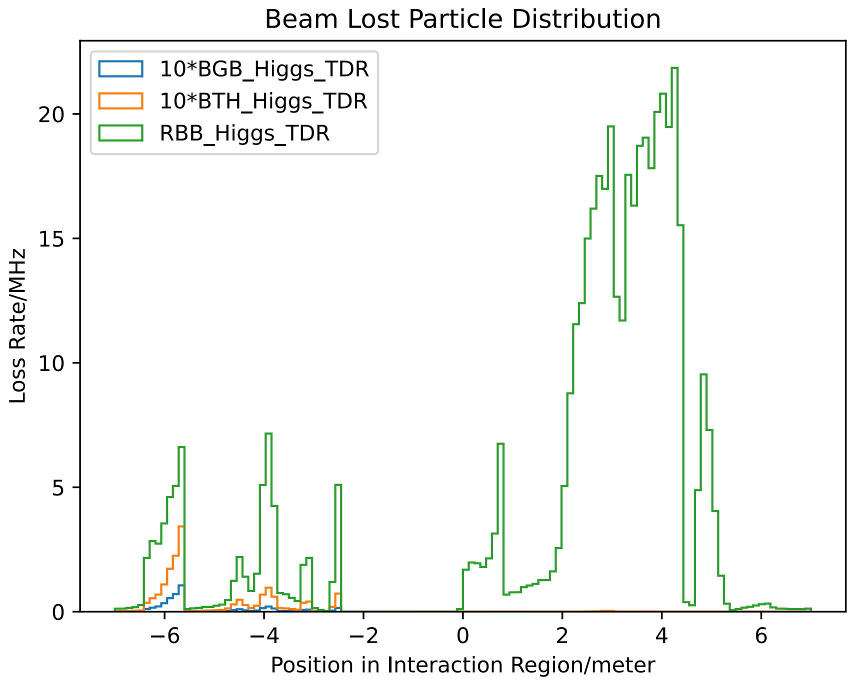
- The diameter of the beampipe in all regions except the IR and collimator is 56mm, with the length of the components itself.
- The drift chambers and dipoles in the IR and 200m before the IR are sliced to 10cm, with aperture set properly.
  - Since the beam-gas coulomb scattering has not been well studied yet, only X apertures is presented.

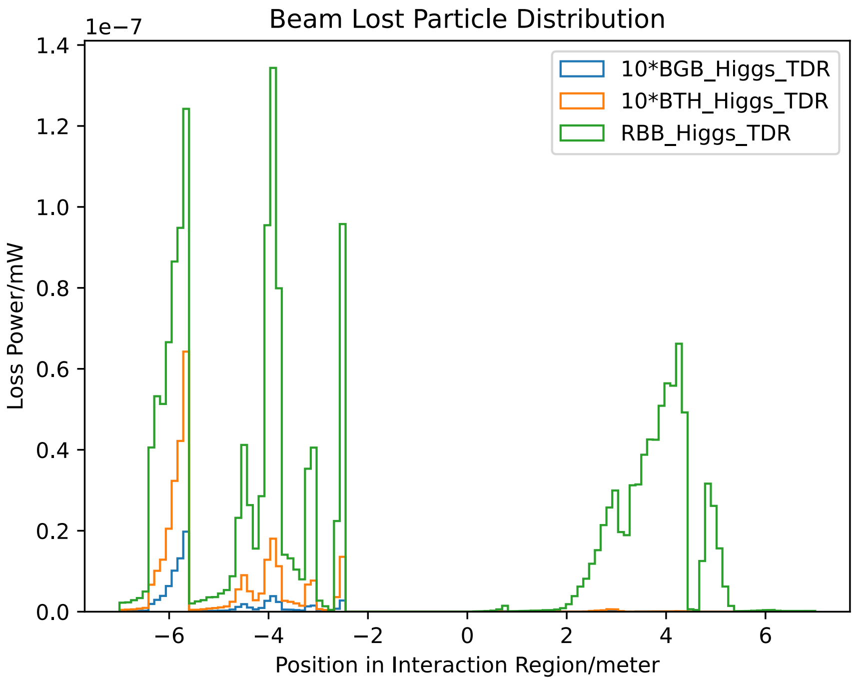




Beam Loss Particles

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



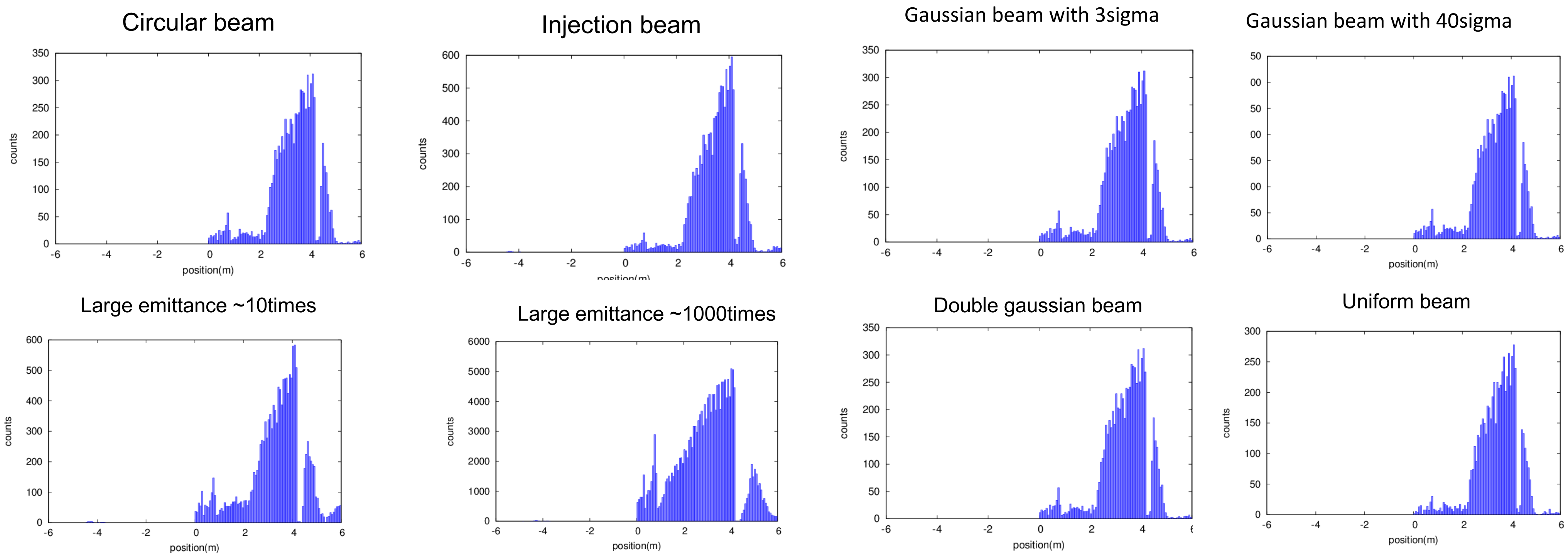


- Upstream Loss Rate is higher than downstream, loss power isn't
  - Quads would be one of the hot-spot, shielding might be needed.

Injection Backgrounds

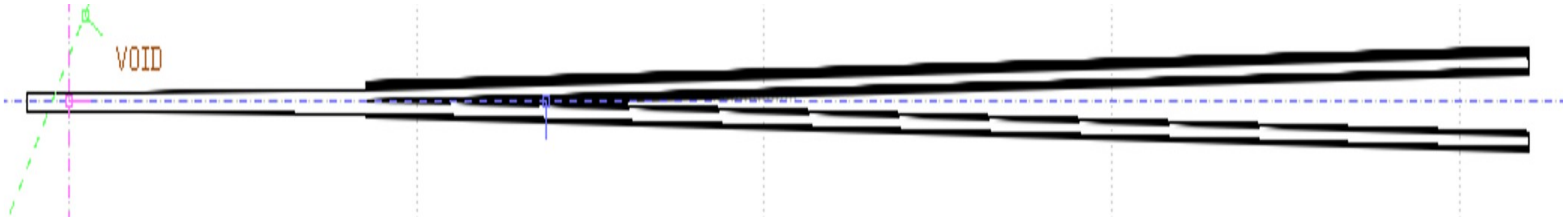
S. Bai

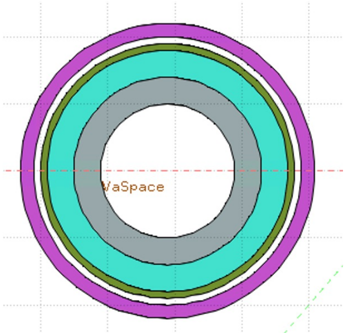
- A preliminary study on the injection backgrounds has been performed:
  - RBB is taken into account in all cases
  - A simplified model of top-up injection beam
  - Tails from imperfectly corrected X-Y coupling after the injection point
  - Some tolerances to imperfect beams from the booster (e.g. too large emittances)
  - non-Gaussian distributions existing/building up in the booster and being injected into the main rings



Beam Pipe Simulation -- FLUKA

- The initial version of shielding of the quads has been performed using FLUKA.
- Pure tungsten IR beam pipe with 4mm thickness without cooling taken into account, simulate the Absorbed Dose on Coil (Region)
- Only Beam-Gas beam loss is taken into account , calculated based on loss distribution from SAD:
    - ~0.00166 Gy/s(0.166rad/s)
    - Safe for Higgs. Other sources on going.

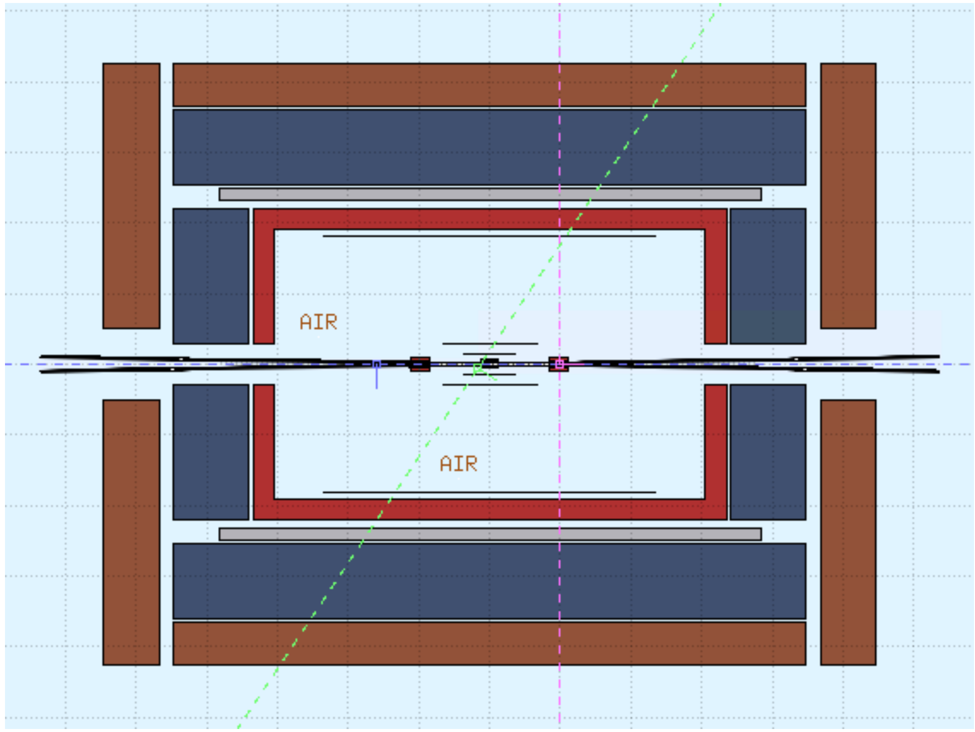




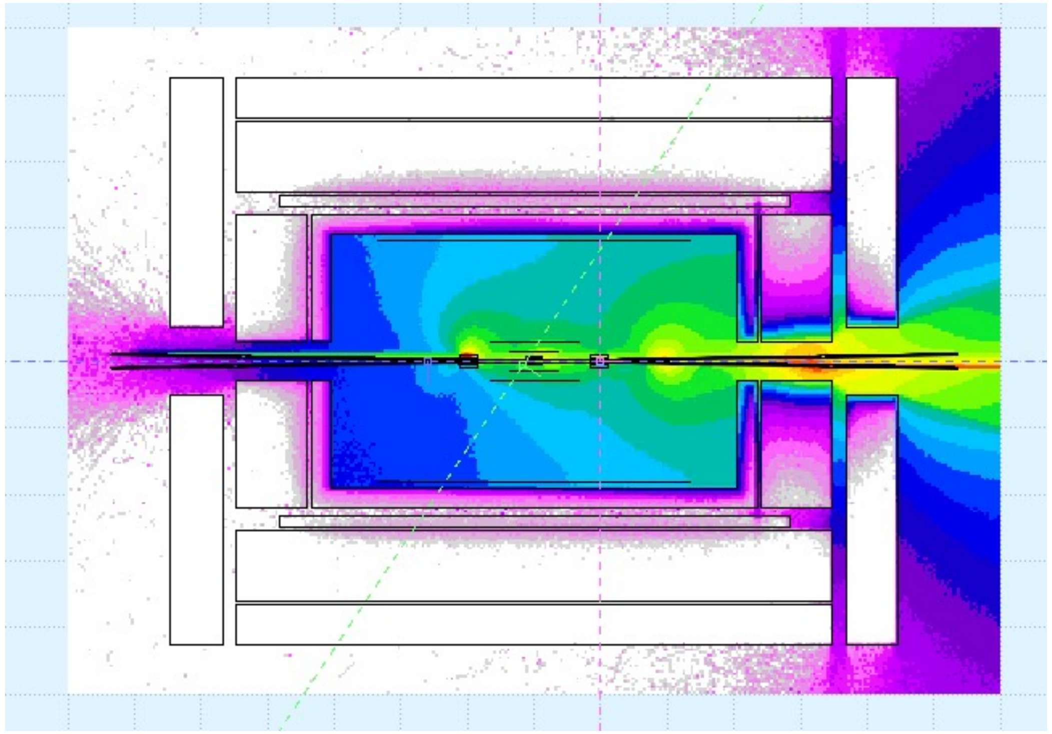
White: Vacuum
Gray: Tungsten Pipe
Light Green: Helium
Heavy Green: Stainless Steel Vassel
Pink: Coil

Detector Simulation -- FLUKA

- The initial version of detector simulation has been performed using FLUKA.
  - The Endcup/Lumical must be taken care of.
  - We plan to improve the accuracy of the model and make comparison.



Sample Model



TID(Sample)

TDR Estimation – with safety factor of 10

- For fast estimation, we try to perform some scaling based on CDR results according to Luminosity.
- The full-detector TDR simulation has been started.
  - We are updating the tools.
- We plan to have double check on detector simulation(Mokka/CEPCSW/FLUKA)

Scaling Results on 1st layer of vertex detector

W. Xu

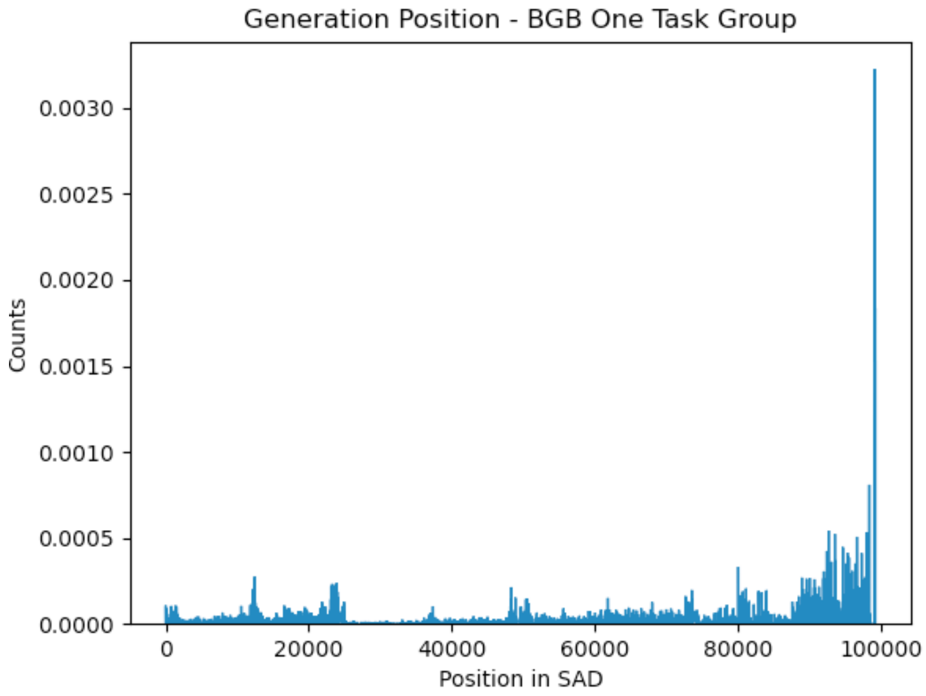
	CDR	TDR(30MW)	TDR(50MW, Upgradable)
Higgs (3T)	2.93	5.00	8.00
Z (2T)	32.1	115.0	184.0

	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)	NIEL($n_{eq}\times10^{12} \cdot cm^{-2} \cdot yr^{-1}$)
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

Simulation Efficiency Improvement

- Currently, we are simulating huge of particles. E.g., for beam gas, ~0.5B particles was generated, tracked, and stored per task group. Usually, we have 50 task groups.
- To company with the limitation of CPU time of 10 hours per task, ~200 sub-tasks are simulated in parallel.
  - For generation/tracking, it usually takes one day in total.
  - For detector simulation, it usually takes ~1 minute CPU time to simulate per particle.
- Huge time/power/storage space consumption.
- Ways to improve:
  - Importing weights.
  - Select high-weight regions to generate BGB/BTH rather than whole ring generation
  - Less turns

On Going Work



Summary & Outlook

- We are moving our study to TDR phase.
  - Layout & Physics design has been updated.
  - The aperture model has been updated.
  - The tracking methods has been updated. New tools/toolkits are needed.
  - More detailed study is on going.
- The optimization and validation of current design is always needed.
  - The BESIII backgrounds experiment was done last/this summer. The data has been shown in Huangchao's talk. We plan to do more in the following years.
  - Validate our BG simulation codes using BEPCII and SuperKEKB.
- List & Study on different beam loss scenarios.
- Any type of collaboration are welcomed.

Thank You

Backup