Study Status on CEPC MDI Background – CDR

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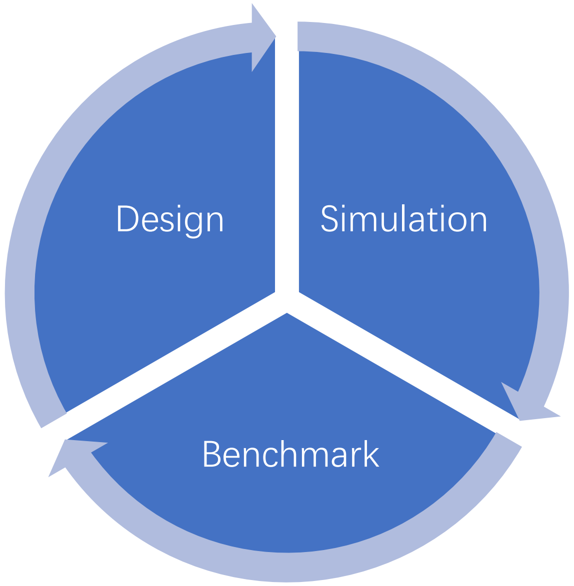
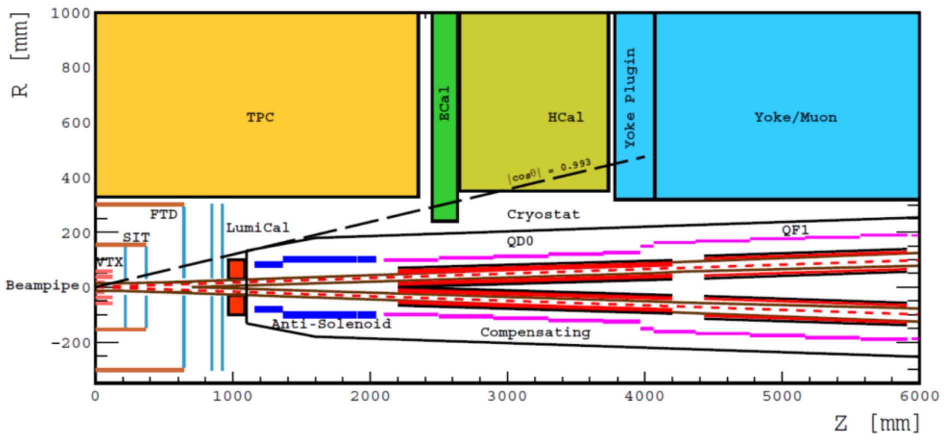
On Behalf of CEPC MDI Working Group

Joint Workshop for the CPEC Physics, Software and New Detector Concept, 2021.4.16

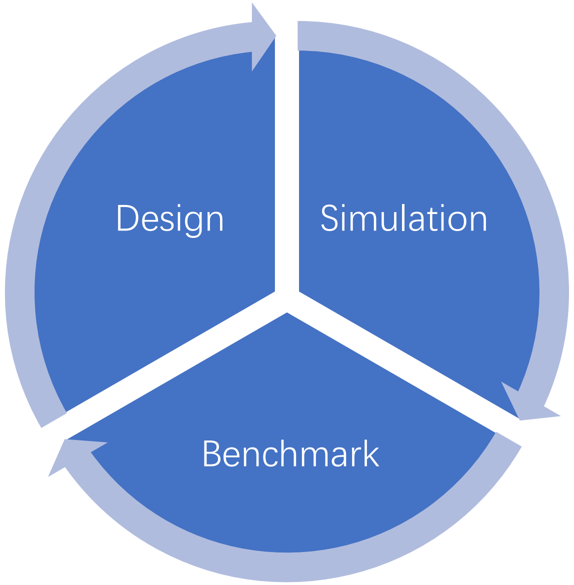
Radiation Backgrounds

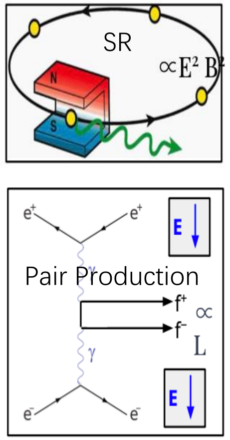




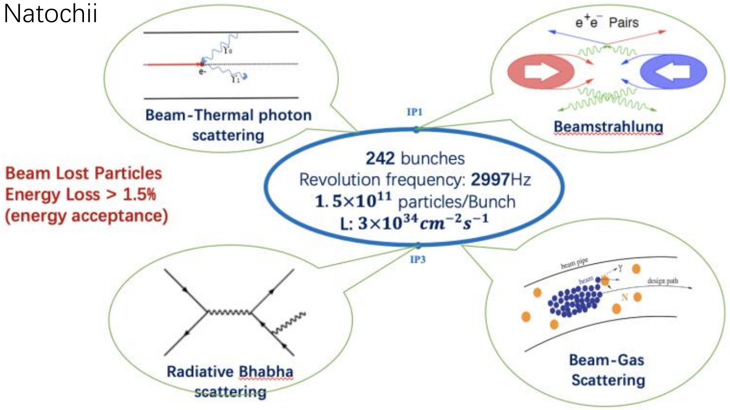
	Higgs	W	Z (3T)	Z (2T)
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch spacing)	**242 (0.68μs)**	**1524 (0.21μs)**	**12000 (25ns+10%gap)**	
Beam current (mA)	17.4	87.9	461.0	
Synchrotron radiation power /beam (MW)	**30**	**30**	**16.5**	
Bending radius (km)	10.7			
Momentum compact (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 $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.54/0.0016	0.18/0.004	0.18/0.0016
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	13.9/0.049	6.0/0.078	6.0/0.04
Beam-beam parameters ξ_x/ξ_y	0.031/0.109	0.013/0.106	0.0041/0.056	0.0041/0.072
RF voltage V_{RF} (GV)	2.17	0.47	0.10	
RF frequency f_{RF} (MHz) (harmonic)	650 (216816)			
Natural bunch length σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	3.26	5.9	8.5	
HOM power/cavity (2 cell) (kw)	0.54	0.75	**1.94**	
Natural energy spread (%)	0.1	0.066	0.038	
Energy acceptance requirement (%)	**1.35**	**0.4**	**0.23**	
Energy acceptance by RF (%)	2.06	1.47	1.7	
Photon number due to beamstrahlung	0.1	0.05	0.023	
Lifetime _simulation (min)	100			
Lifetime (hour)	**0.67**	**1.4**	**4.0**	**2.1**
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP *L* ($10^{34}cm^{-2}s^{-1}$)	**2.93**	**10.1**	**16.6**	**32.1**

Radiation Backgrounds

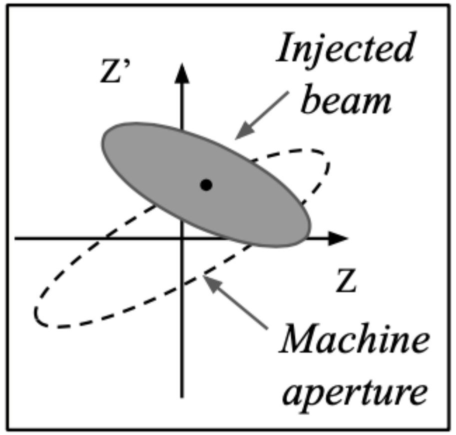




A. Natochii



A. Natochii



Photon BG

Beam Loss BG

Injection BG

- Photon BG and Beam Loss BG were simulated using different tools. Injection BG is ignored for now.
  - Cross-check and benchmark needed.
- Other BGs are planned to study.

Background	Generation	Tracking	Detector Simu.
Synchrotron Radiation	BDSim	BDSim/Geant4	Mokka
Beamstrahlung/Pair Production	Guinea-Pig++	SAD	
Beam-Thermal Photon	PyBTH		
Beam-Gas Bremsstrahlung	PyBGB		
Radiative Bhabha	Bbbrem/PyRBB		

Updates since Original CDR(2018)

- Update on Design
- Update on Tracking Method
- Update on Simulation & Results

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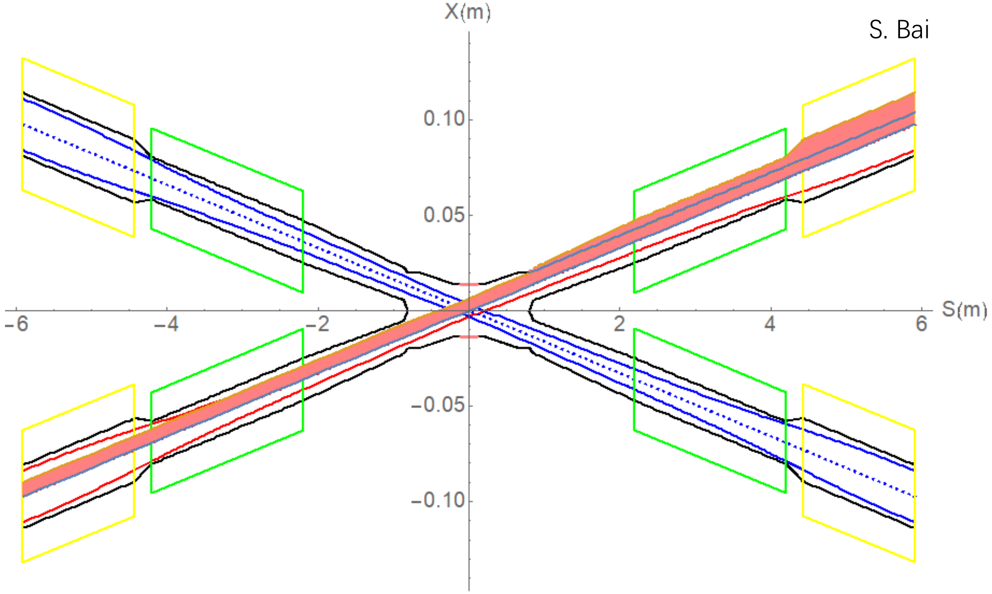
Starting with Synchrotron Radiation

- Original central beam pipe design need to be improved.
- Synchrotron radiation should be dealt with high priority at circular machines when designing the interaction region

Revised beam pipe design to achieve
No direct SR photons hitting the central beam pipe except the extreme beam conditions (e.g. beam off orbit due to magnet errors)

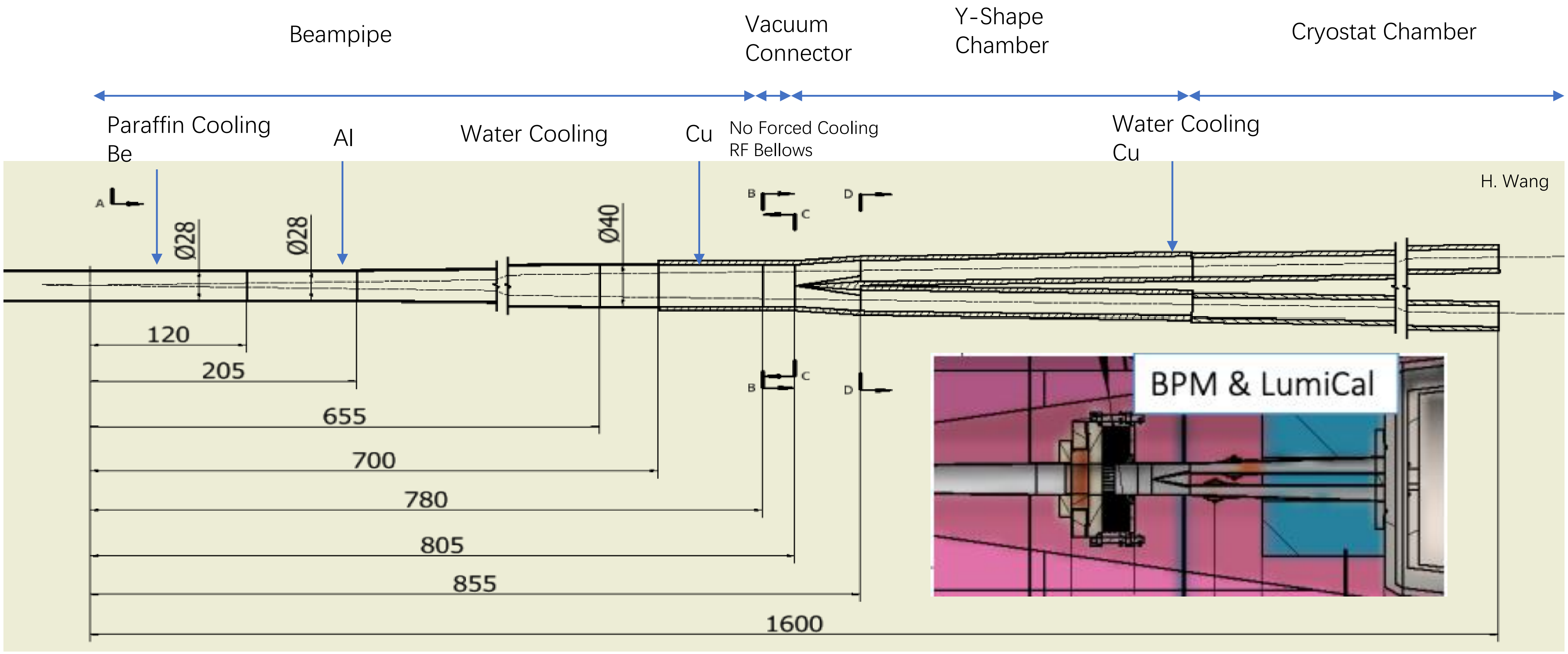


S. Bai

	Power Deposition	Average Power Density
0.805~0.855m	16W	88.9W/cm^2
0.855~2.2m	12.3W	2.54W/cm^2
QD0(2.2m~4.2m)	2.79W	0.39W/cm^2
QD0~QF1(4.2~4.43m)	36.1W	43.6W/cm^2
QF1(4.43m~5.91m)	3W	0.56W/cm^2

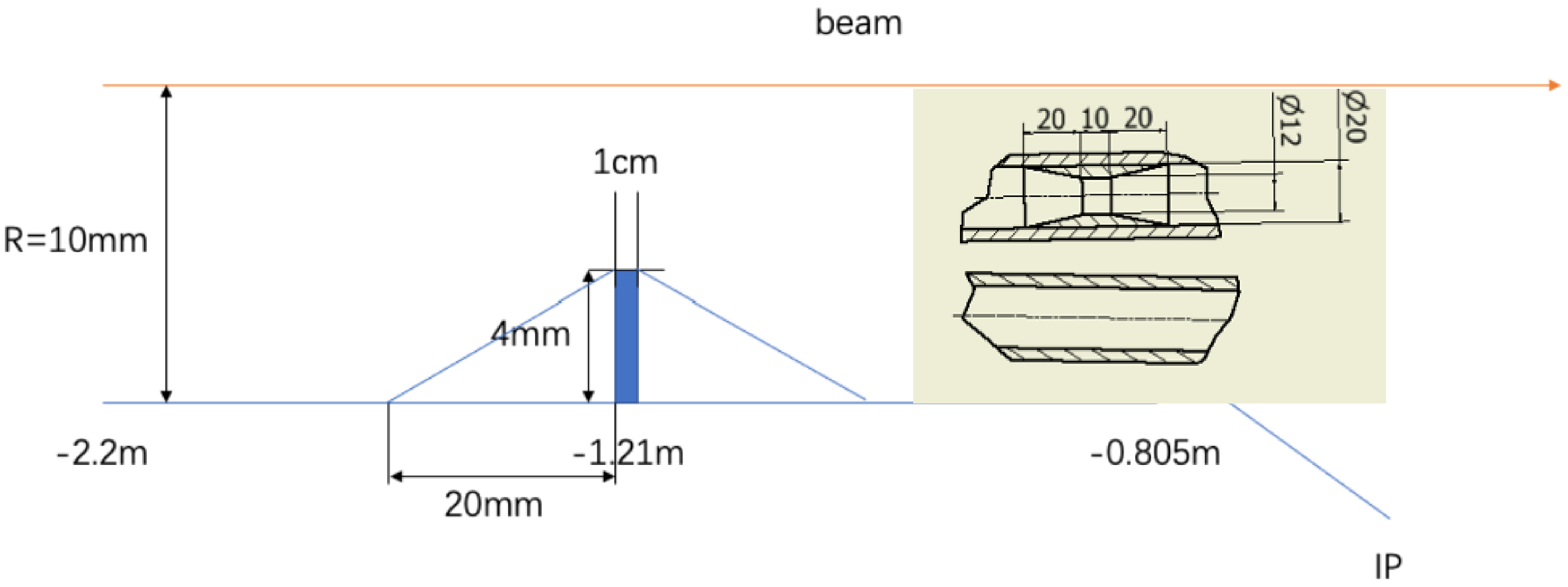
Revised beampipe design

Nearly 20 versions tried in last 10 months

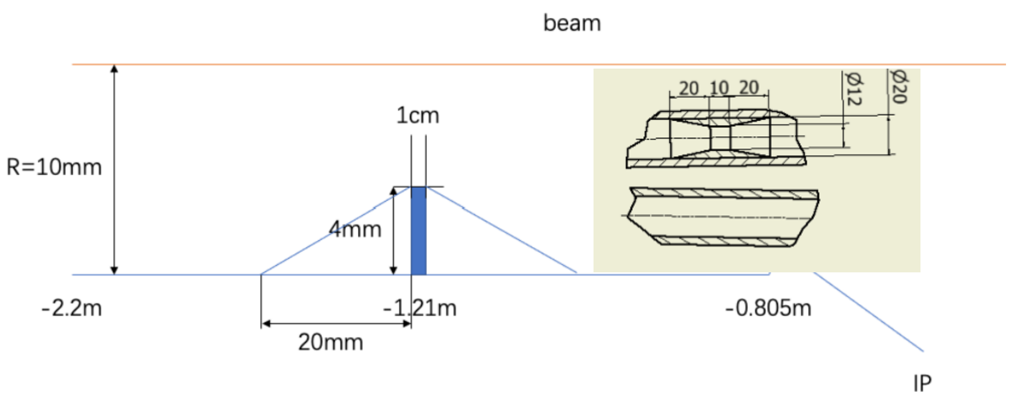


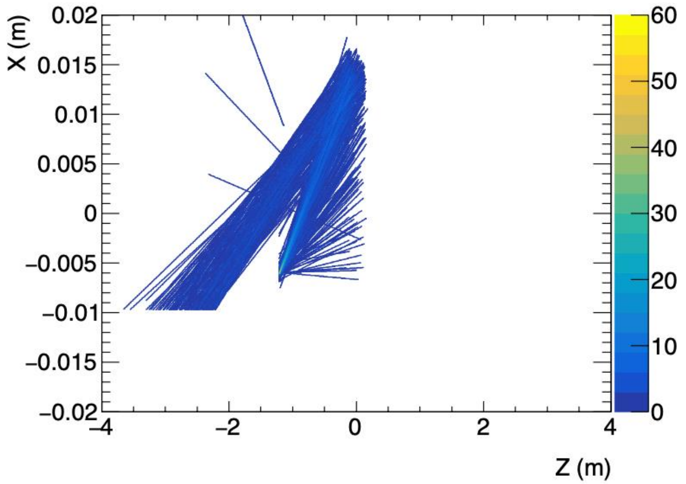
Mitigation – SR Mask

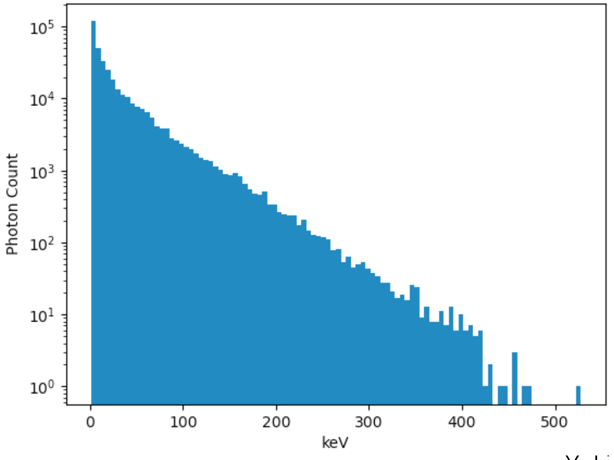
- New mask design:
  - Tungsten
  - 4mm height
  - 10mm long
  - Locates at -1.21m



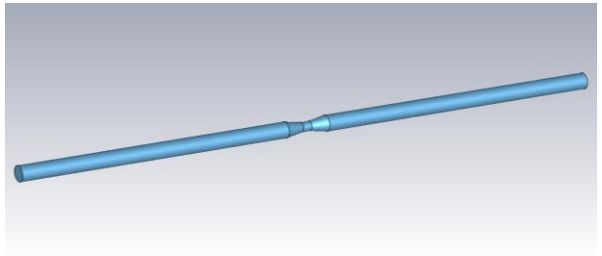
Mitigation – SR Mask

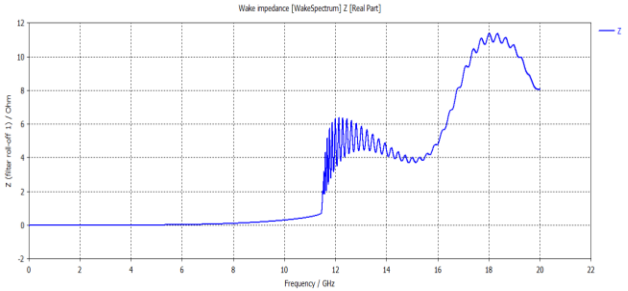






Y. Liu

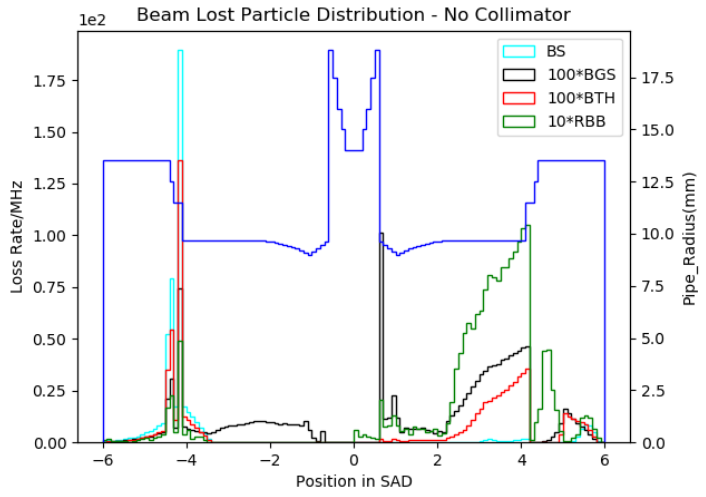


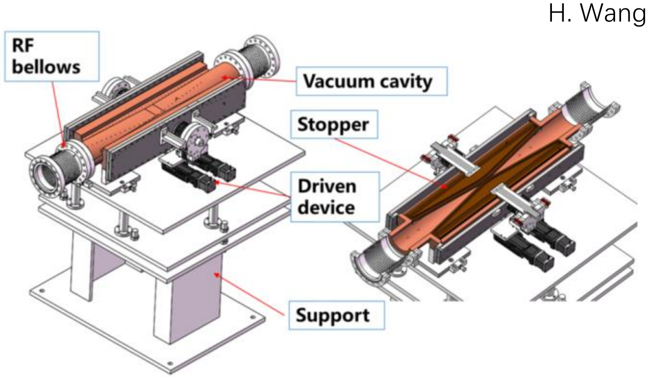


- Lots of photons are secondaries, generated within QD0
- ~320 photons/BX could hit Be beampipe, with a.e. ~100keV
  - $\sim 1.44 \times 10^{-8}$ W on Be beampipe

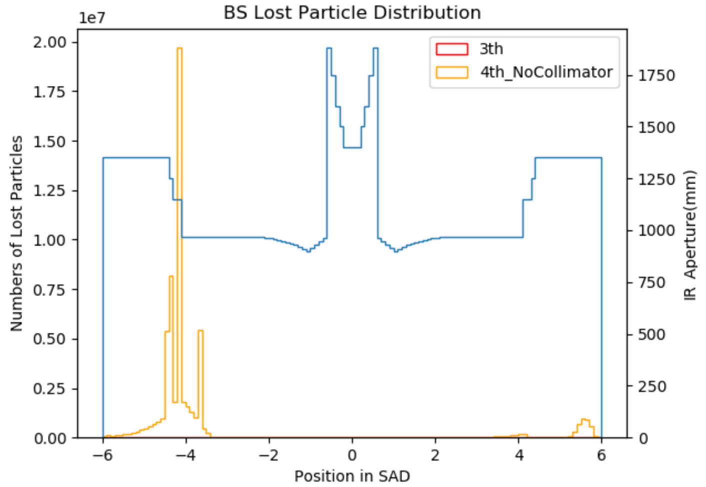
Loss factor(V/pc)	Power &Higgs	Power &W	Power &Z(CDR)	Power &Z(High Lum)
8.69*10^{-4}	0.36 w	1.47 w	**5.13w**	22.61w

Mitigation – Collimator





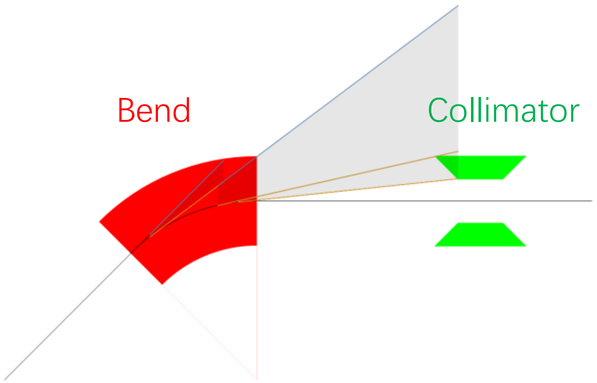
- 2 sets of horizontal collimators have been put in ring.
  - Upstream beam loss have been reduced to low level.
  - We are sure to need more.
- Preliminary design of the movable collimator has been done.
  - Impedance and the SR impact on collimator has been calculated.



S. Bai

Name	Location	From IP
APTX1	D1I.1897	2139.06
APTX2	D1I.1894	2207.63
APTX3	D1O.10	1832.52
APTX4	D1O.14	1901.09

S. Bai



Updates since Original CDR(2018)

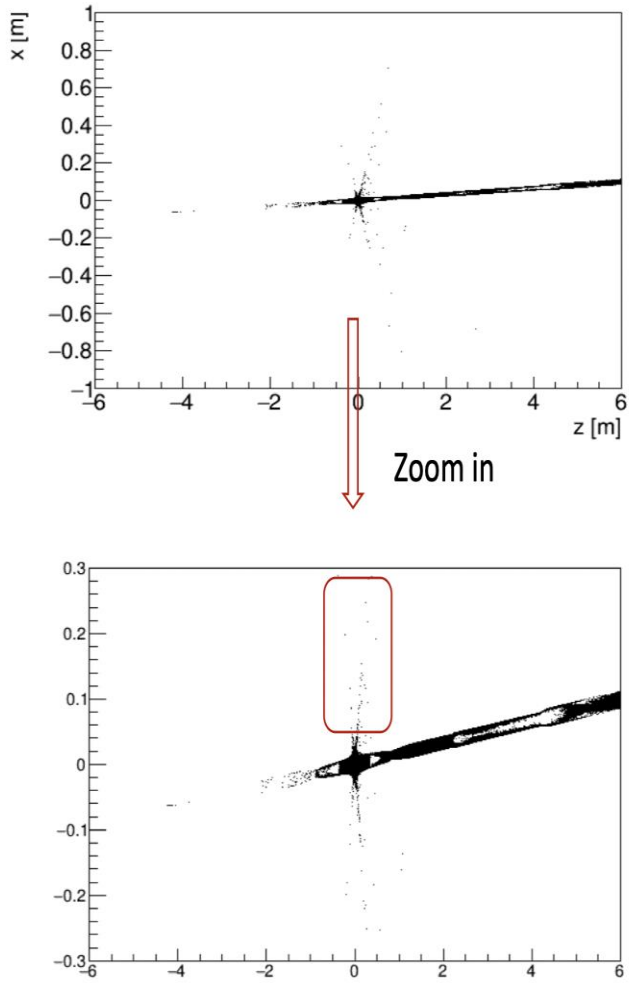
- Update on Design
- Update on Tracking Method
  - External Magnetic Field Implement
  - Output one step before default
  - Generate BGB/BTH in whole ring
- Update on Simulation & Results

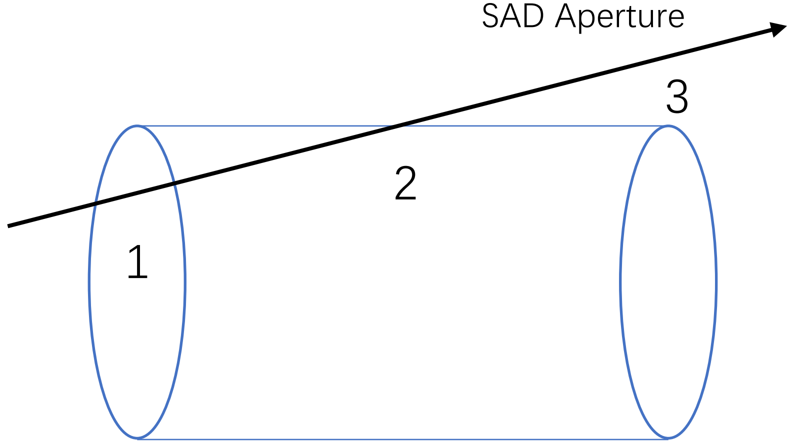
External Magnetic Field in G-Pig++

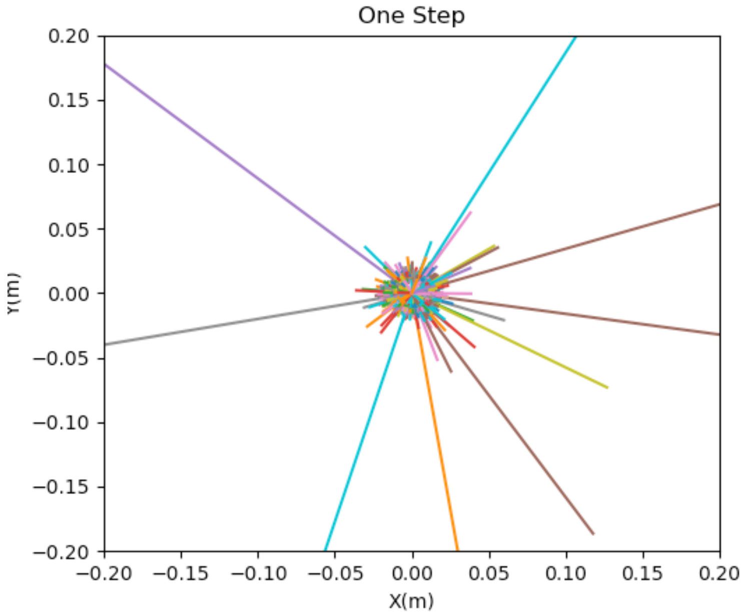
- Guinea-Pig++ is used to simulation pair production.
- The interaction of two bunches is simulated by a grid passing through another grid.
- Guinea-Pig++ was developed for linear colliders which have bunch size in the order of nanometers, while the bunch size of the CEPC is in the order of millimeters. Longer bunch size means longer tracking path. As a result, secondary particles can travel to a region where the external field produced by the solenoid is not negligible, before the two bunch pass through each other completely. Therefore the external magnetic field produced by solenoid has been integrated into the program for the simulation of deflection to pairs by Xu Wei.

Output one step before default

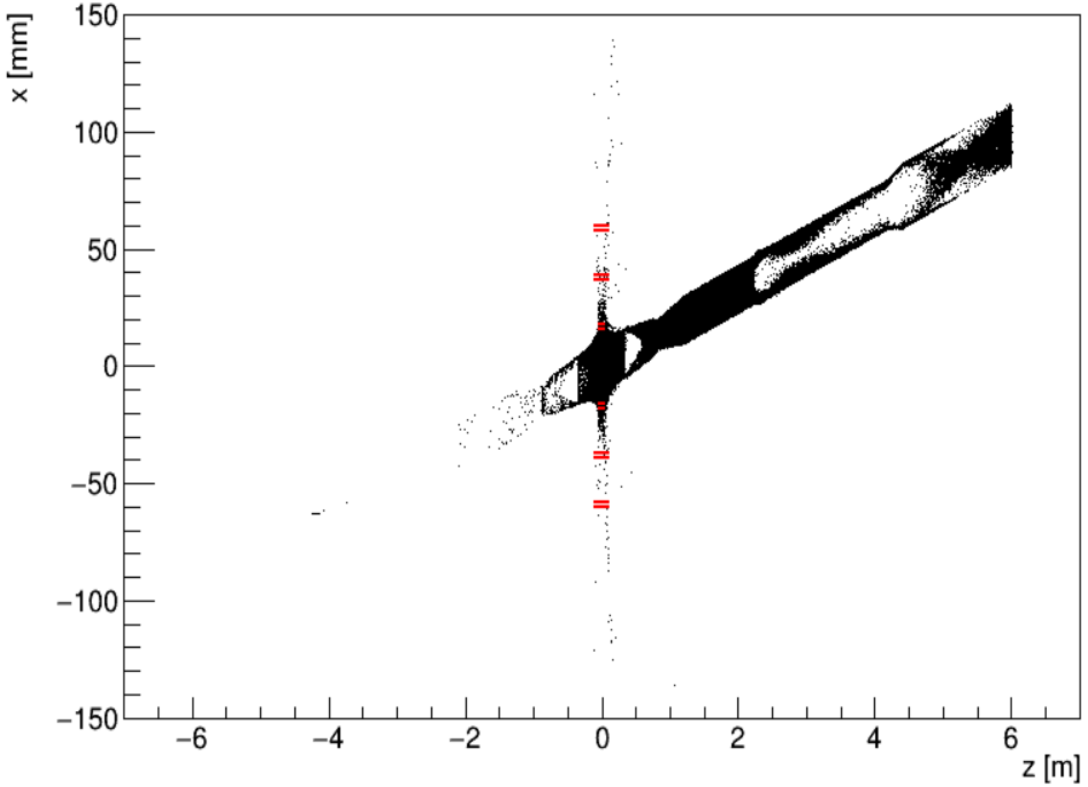
- Lots of loss particles are “outside”of the beampipe.
  - Due to the tracking mechanism of SAD
- The improvement of the tracking method is needed.

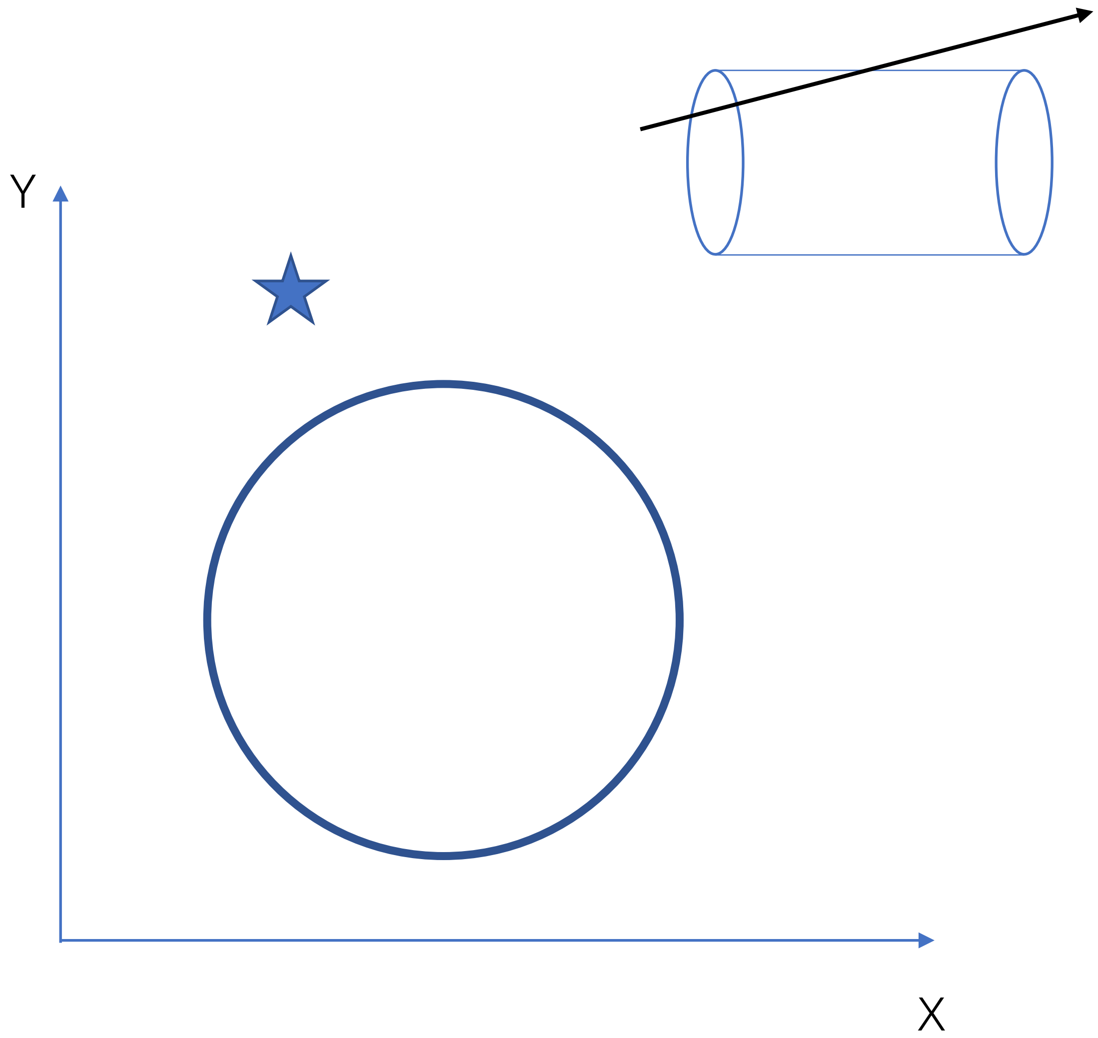






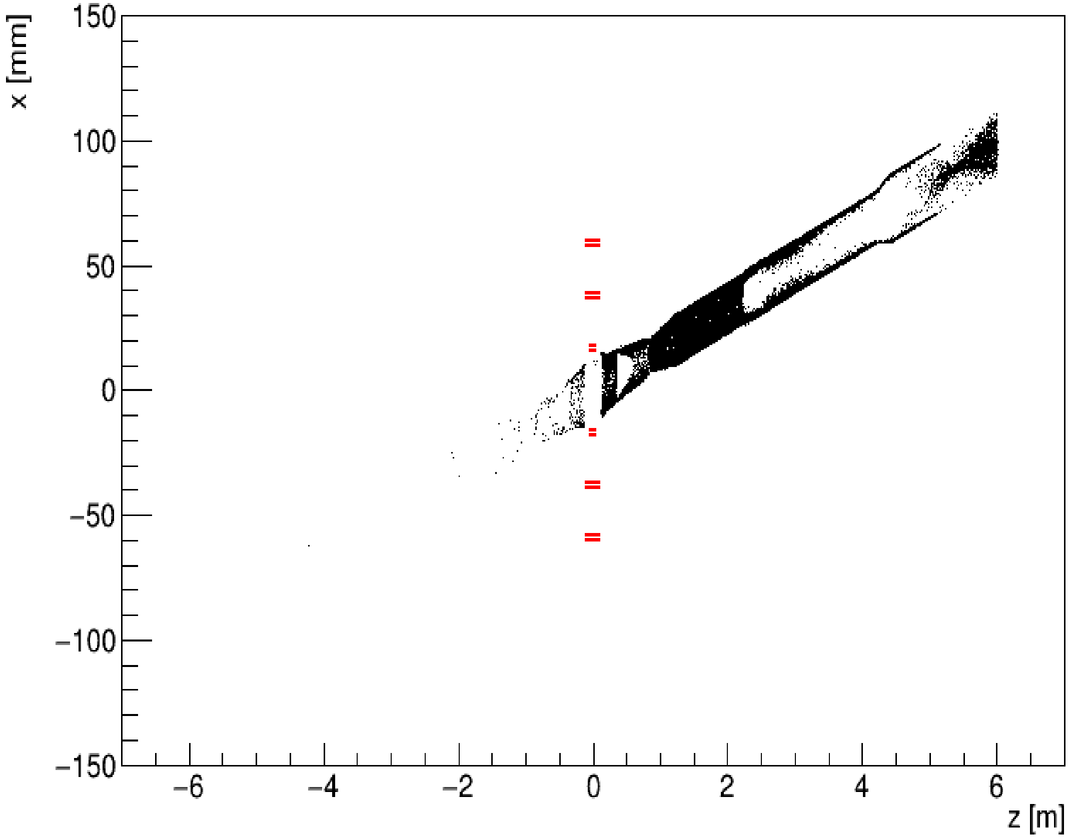
Tracking Method Improvement

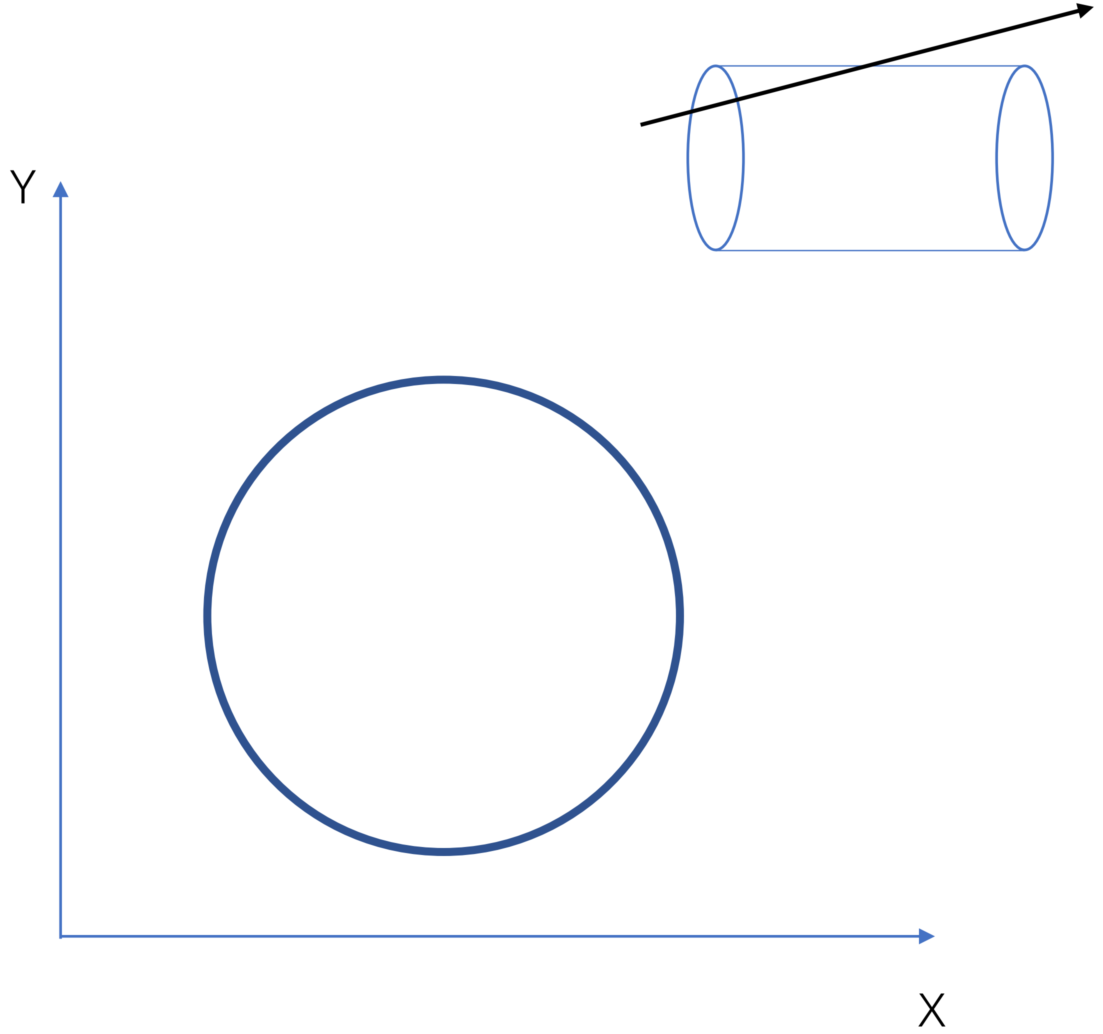




Method 1 – Out

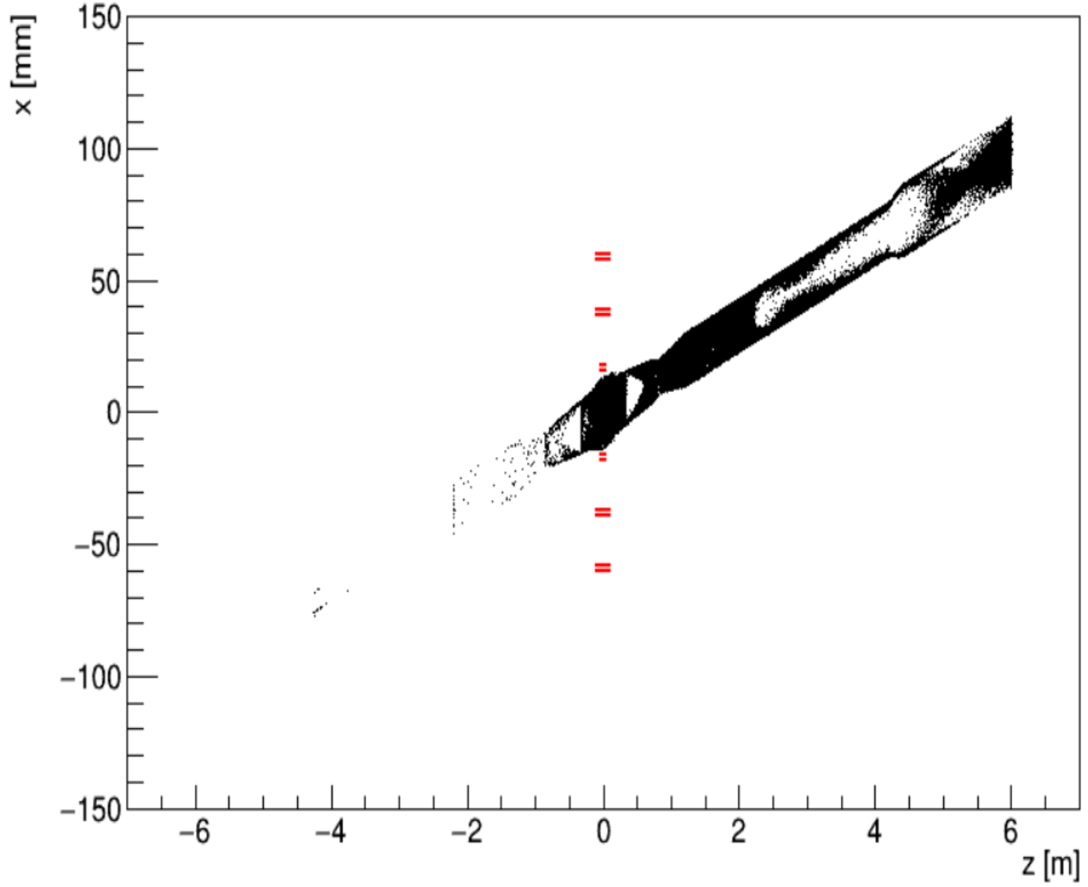
Tracking Method Improvement

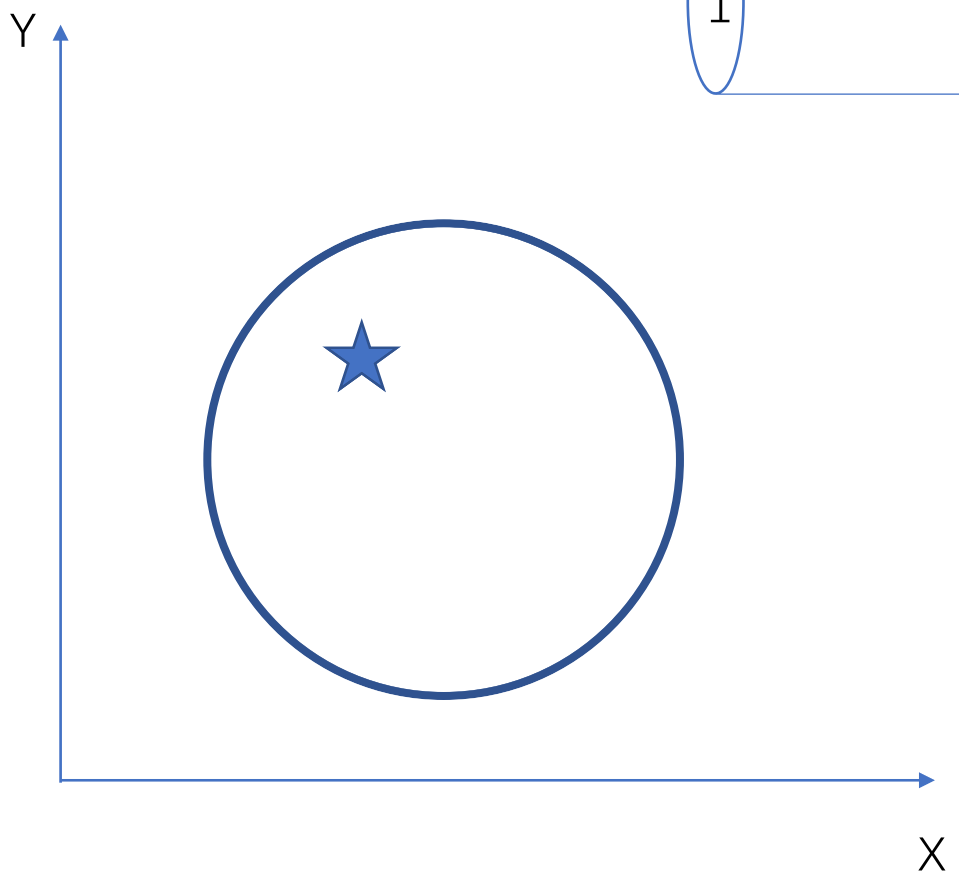


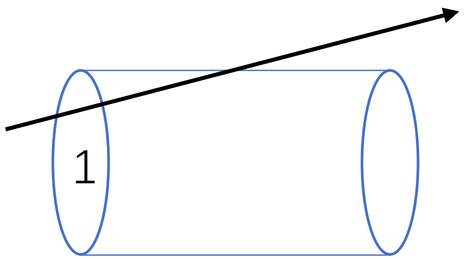


Method 2 – Cut

Tracking Method Improvement

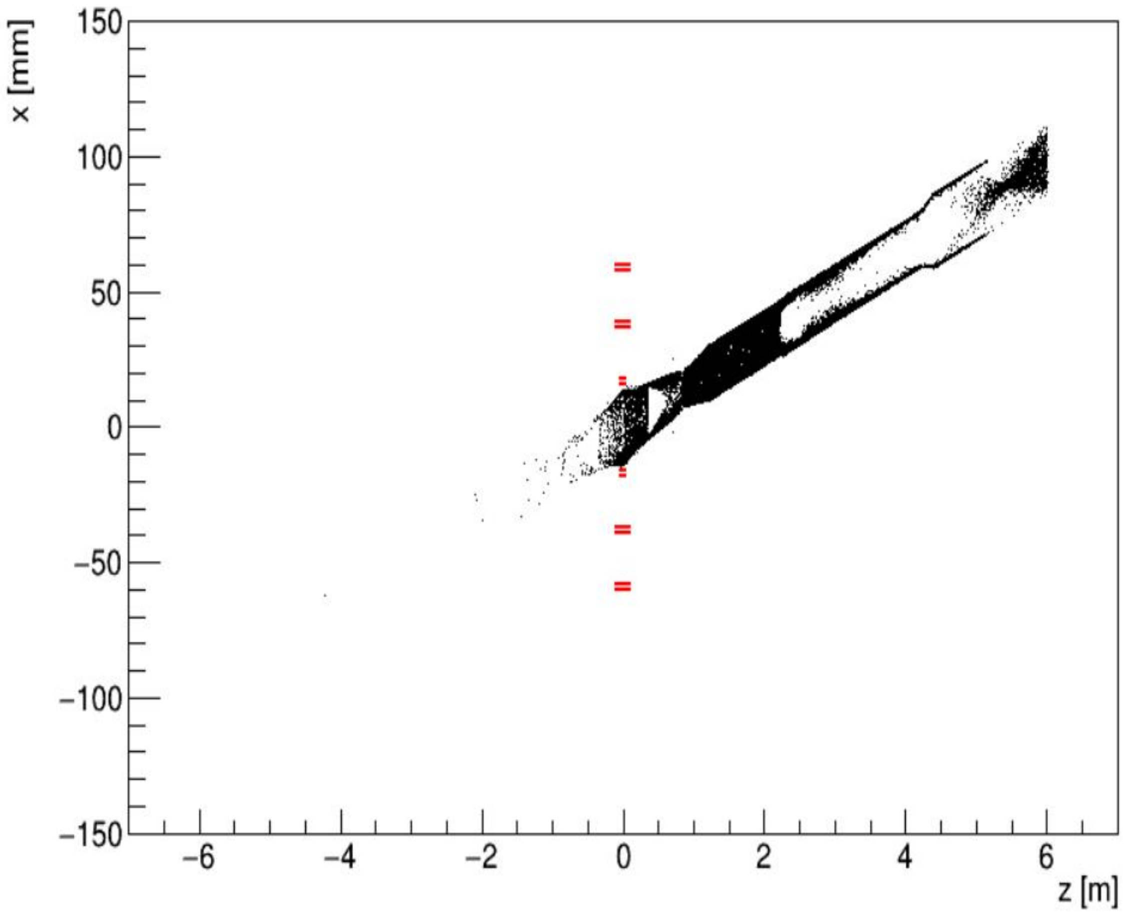


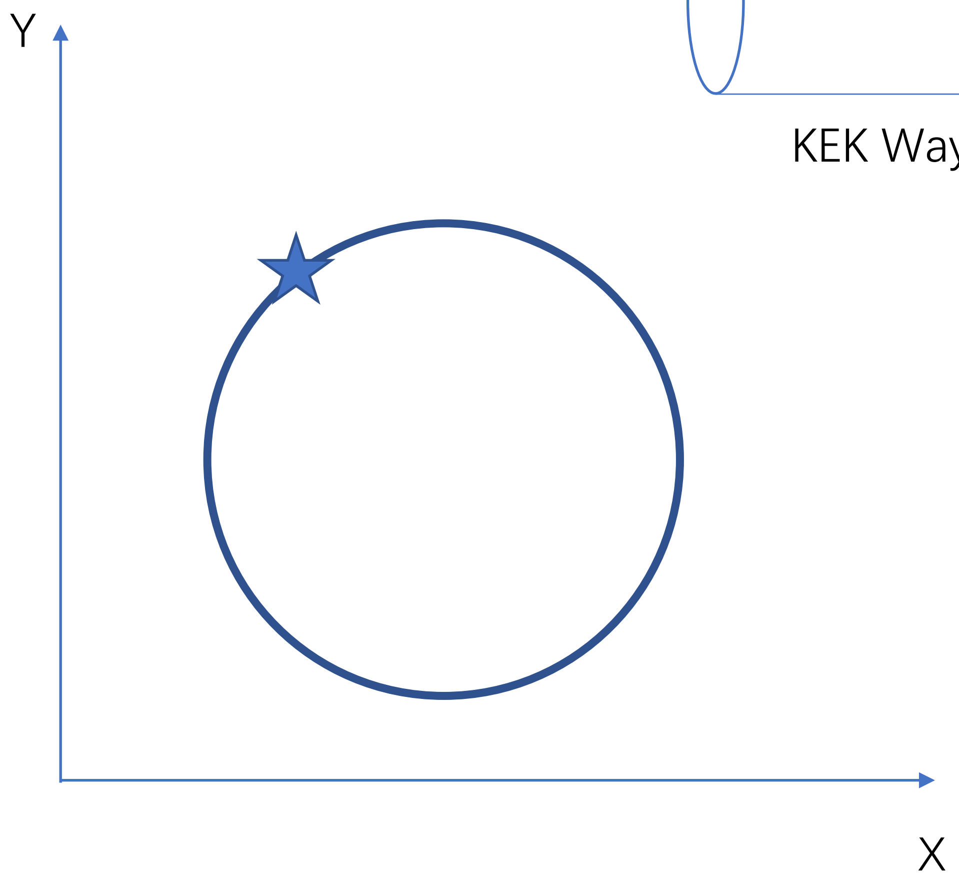


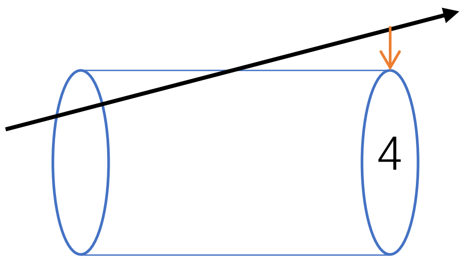


Method 3 – Before

Tracking Method Improvement



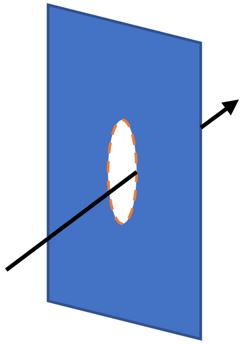




KEK Way

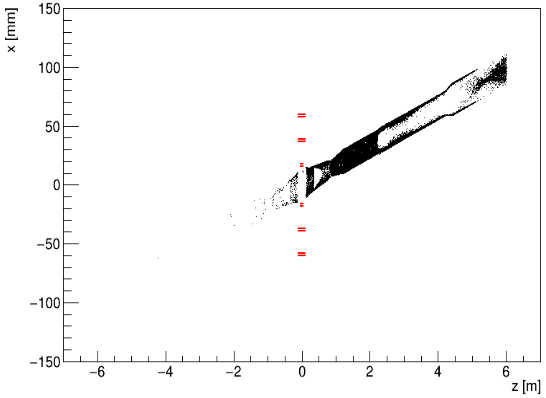
Method 4 – Move

Tracking Method Improvement

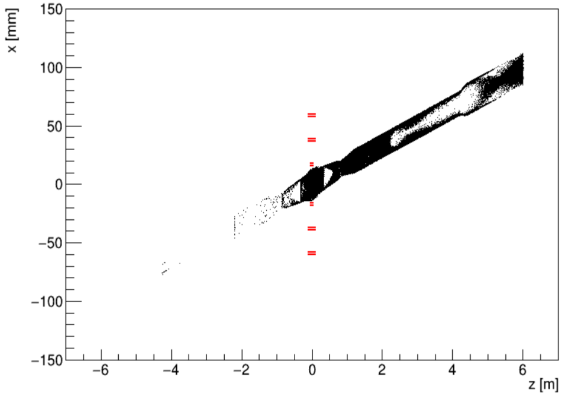


	Method 1 - Out	Method 2 - Cut	Method 3 - Before	Method 4 - Move
Hit Density($cm^{-2} \cdot BX^{-1}$)	0.155	0.004	0.03	0.0066
TID($krad \cdot yr^{-1}$)	244.603	2.072	20.3	6.04
1 MeV equivalent neutron fluence ($n_{eq} \cdot cm^{-2} \cdot yr^{-1}$)	6.62×10^{11}	4.03×10^{9}	3.97×10^{10}	1.12×10^{10}

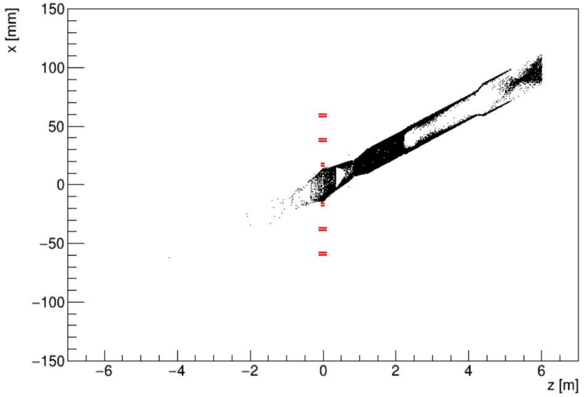
Method 1 – Out



Method 2 – Cut



Method 3 – Before



Method 4 – Move

	Method 1 - Out	Method 2 - Cut	Method 3 – Before	Method 4 – Move
Hit Density($cm^{-2} \cdot BX^{-1}$)	0.155	0.004	0.03	0.0066
TID($krad \cdot yr^{-1}$)	244.603	2.072	20.3	6.04
1 MeV equivalent neutron fluence ($n_{eq} \cdot cm^{-2} \cdot yr^{-1}$)	6.62×10^{11}	4.03×10^{9}	3.97×10^{10}	1.12×10^{10}

Generating BGB/BTH in Whole Ring

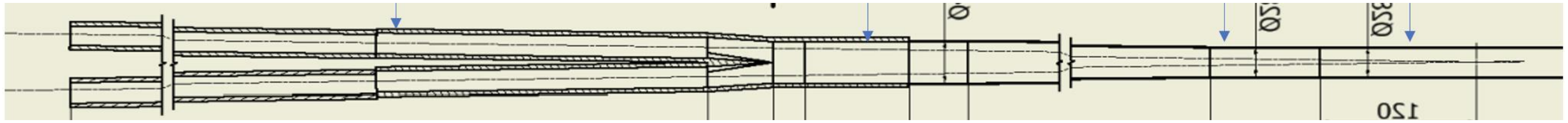
- In previous work, we only generate BGB/BTH in -200~6m.
- Now we generate BGB/BTH in whole ring, at the beginning of every components which length is longer than 0.001m.
- We insert the aperture with “real” radius between any two components.
  - In “double pipe” region, we use the real radius of the aperture.
  - In “single pipe” region, we use the smallest radius.
- Then we track the scattered particles for multi turns, using the SAD built-in TrackParticle function with LOSSMAP, FLUC, RFSW & RAD ON(SAD Version 1.1.6.16.3k64).

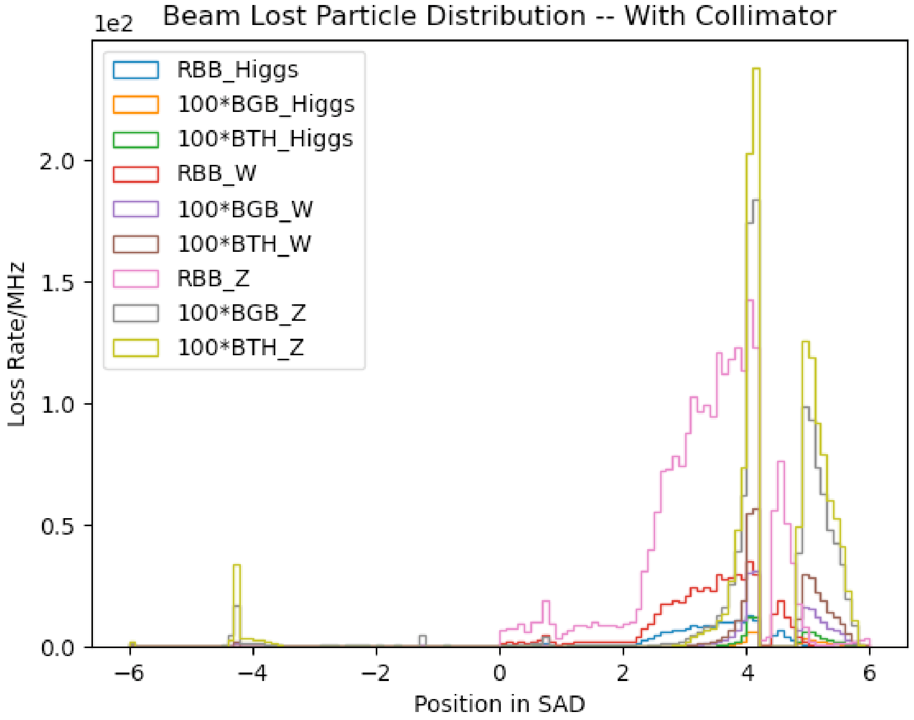
Updates since Original CDR(2018)

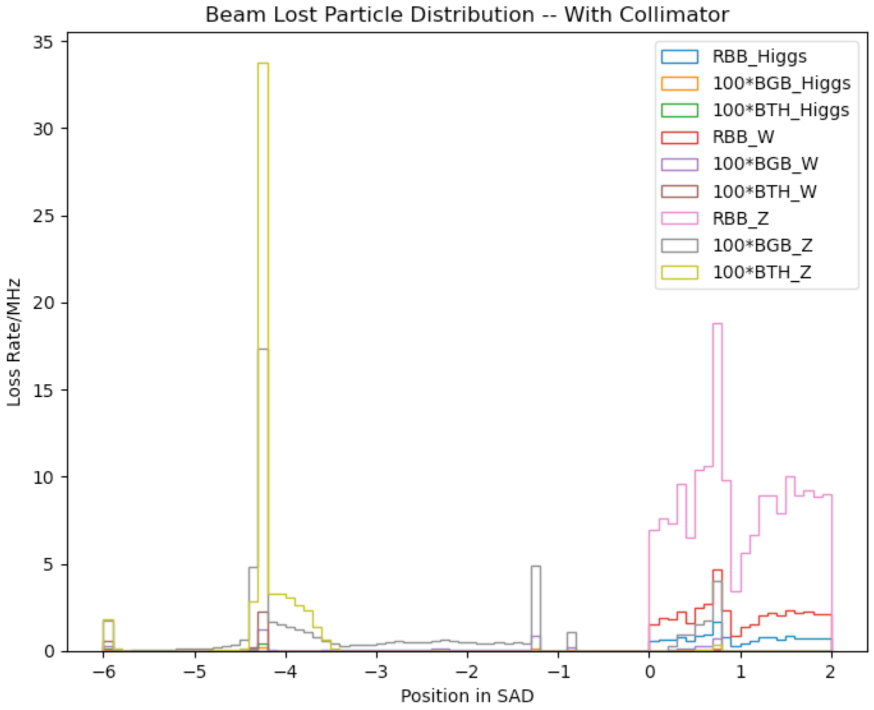
- Update on Design
- Update on Tracking Method
- Update on Simulation & Results

Lost distribution

- Downstream lost is higher with collimators.
- The lost in downstream magnet is significant.
    - Mitigation and shielding are needed. The design and simulation is started.

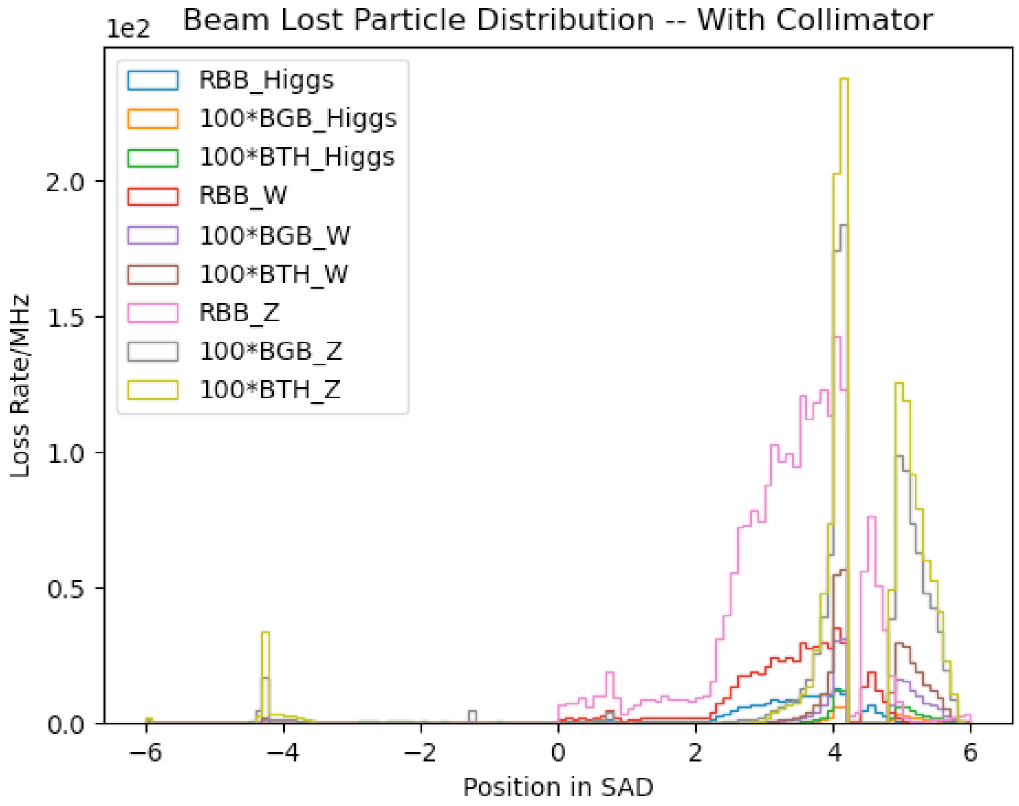




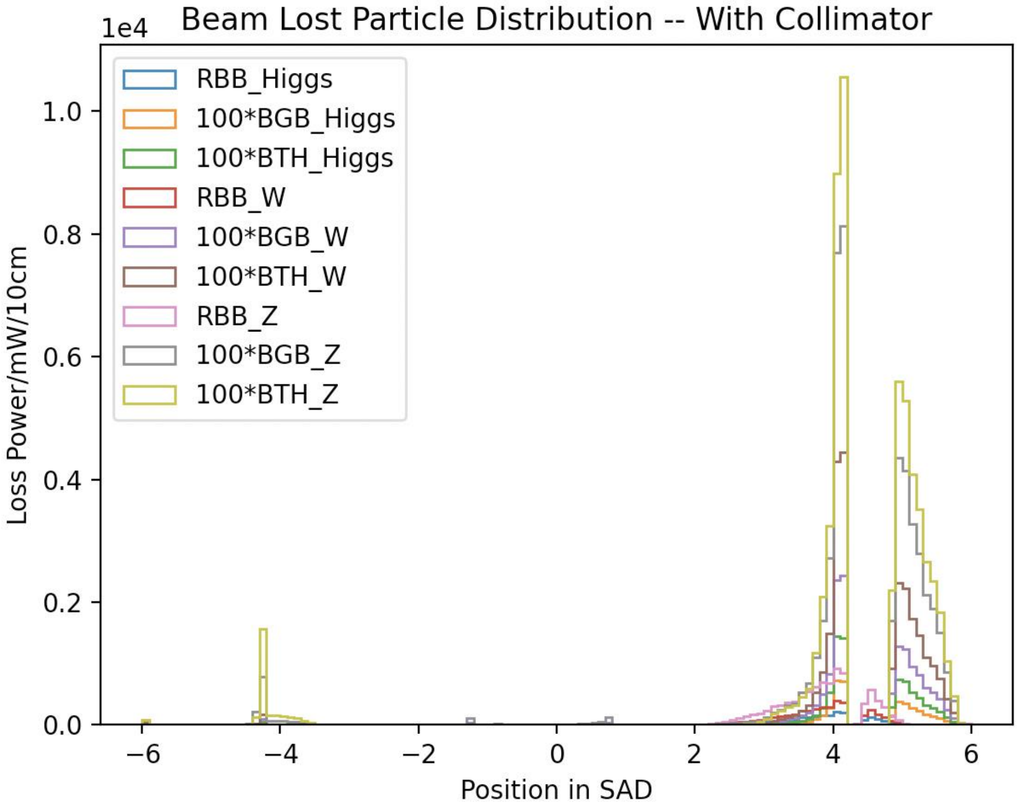


Lost distribution

- The loss power due to beam loss background is low.
  - < 1w / 10cm



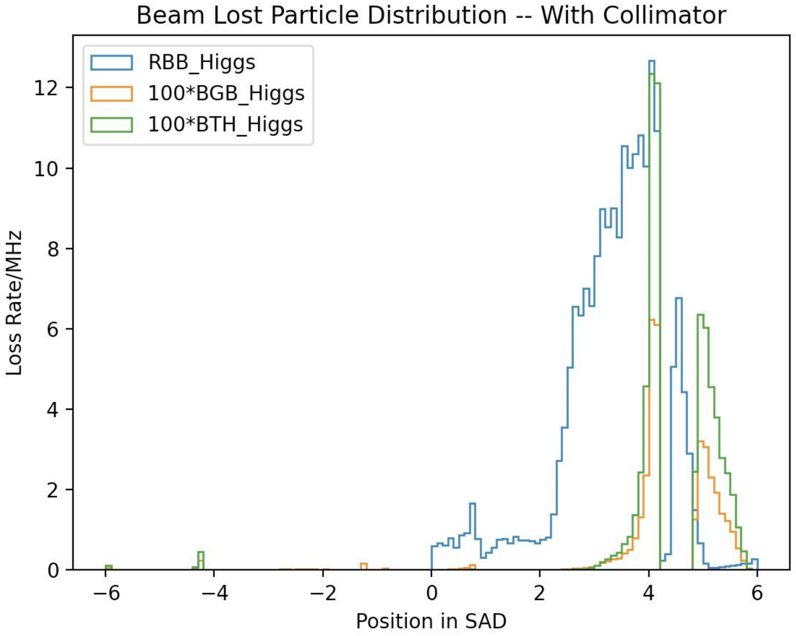
Loss Rate



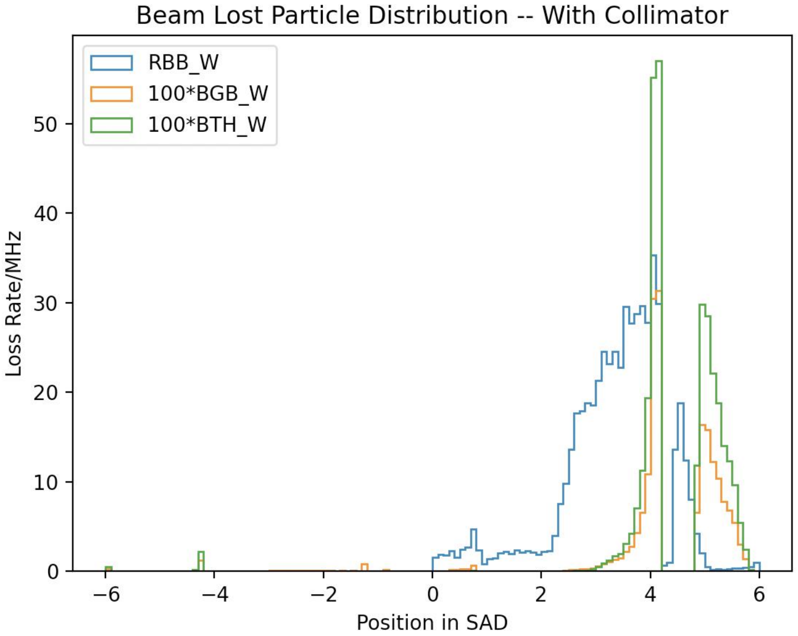
Loss Power

Lost distribution

- Loss Rates increases with particles number increasing.
- RBB loss is much higher than the other two.
  - Consistent with beam lifetime.



Higgs



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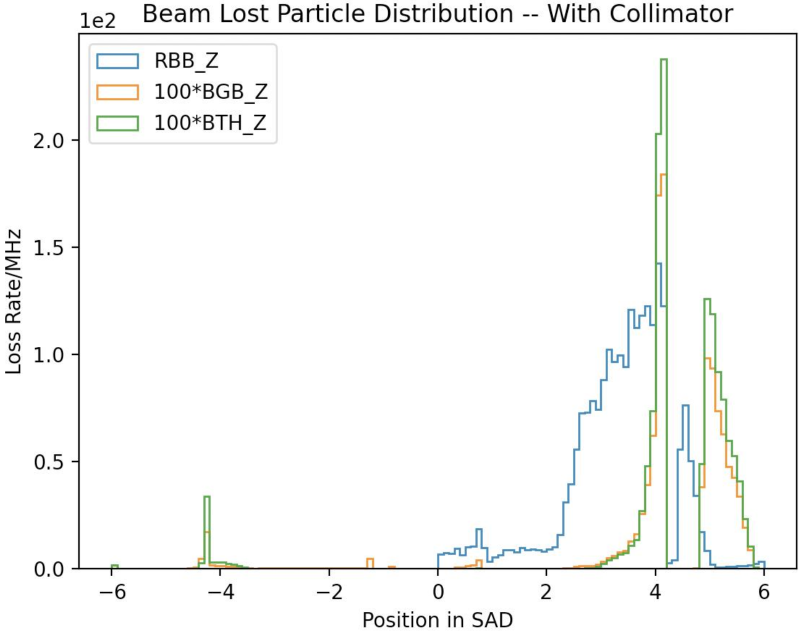


Z

Detector Impact

- SR Hit Number on Be beam pipe per bunch crossing.

	Higgs	W	Z
Hit Number	~320	~28	<1

- Preliminary results on 1st layer of vertex. Safety factor of 10 applied.

Background	Hit Density($cm^{-2} \cdot BX^{-1}$)			TID($Mrad \cdot yr^{-1}$)			1 MeV equivalent neutron fluence ($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)		
	Higgs	W	Z	Higgs	W	Z	Higgs	W	Z
Pair production	1.8	1.2	0.4	0.50	2.1	5.6	1.0	3.8	10.6
Beam Gas	0.4	0.4	0.2	0.36	1.3	4.1	1.0	3.6	11.1
Total	2.17	1.6	0.6	0.86	3.4	9.7	2.0	7.4	21.7
Total_oCDR	2.4	2.3	0.25	0.93	2.9	3.4	2.1	5.5	6.2

- Take Mask into Account(Higgs):

Background	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($Mrad \cdot yr^{-1}$)	1 MeV equivalent neutron fluence ($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)
Beam Gas	0.4	0.39	1.0

Benchmark – Experiments

- Important to validate the modellings and Monte Carlo Simulation codes for the CEPC beam background simulation with real data where they are applicable.
  - BEPC II/BES III, SuperKEKB/Belle II, LEP I/II…
- Basic Principles – Key Parameters & Distinguish
  - Single beam mode: three dominant contributions from Touschek, beam-gas and electronics noise & cosmic rays.
  - $O_{single} = O_{tous} + O_{gas} + O_{noise+\mu} =$
$$S_t \cdot D(\sigma_{x'}) \cdot \frac{I_t \cdot I_b}{\sigma_x \sigma_y \sigma_z} + S_g \cdot I_t \cdot P(I_t) + S_e$$
  - Double beam mode: additional contributions from luminosity related backgrounds, mainly radiative Bhabha scattering
  - $O_{total} = O_{e^+} + O_{e^-} + O_{\mathcal{L}}$(Ideal)
- We hope to perform another run of BG experiment in June
  - No Beam backgrounds has been taken(Last Friday, Cosmic + Electronic)
  - Two Weeks for Single Beam(e-/e+). And the end of this year's BESIII physics run.
  - Experimental Data for luminosity related.

Summary & Outlook

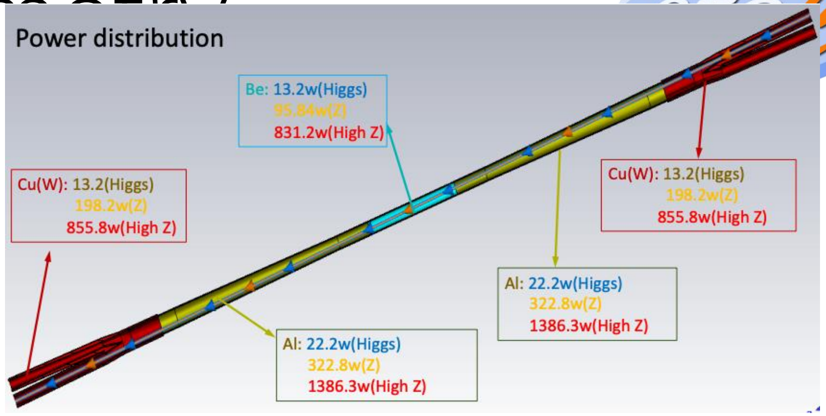
- The study based on CDR is getting finish.
  - The finalization of the central beam pipe design has been determined.
  - Mask has been designed, BG simulation and thermal analysis are performed based on new design.
  - Tracking Method has been updated and applied.
  - Shielding design of Final Focusing system has been started.
- We plan to benchmark our study with experiments
  - Using BEPCII/BESIII, hope to be done in June.
- We consider to move to high luminosity design in coming months.

Thank You

Backup

HOM analysis for asymm

- Maximum HOM Heat load at High-Lumi Z
  - 415.6(Be) + 1386.3(Al) + 855.85 (Cu) W

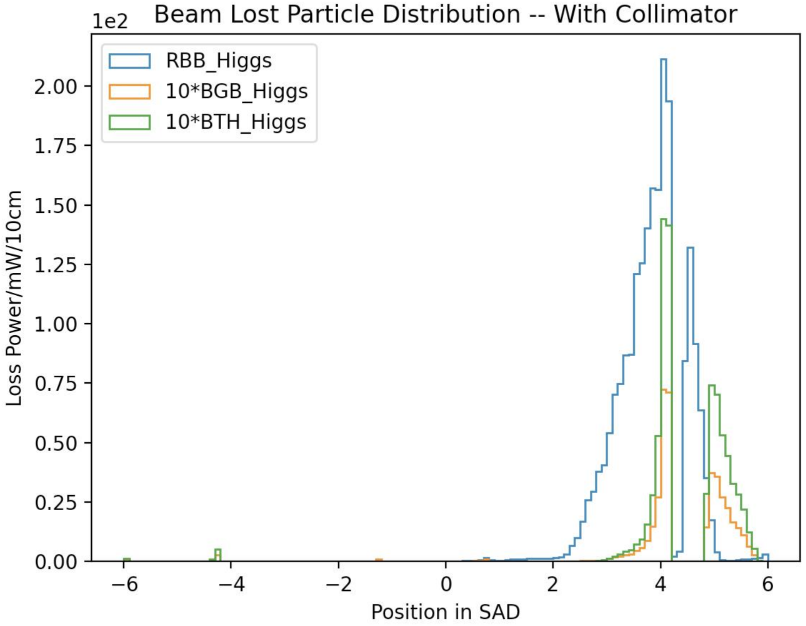


Y. Liu

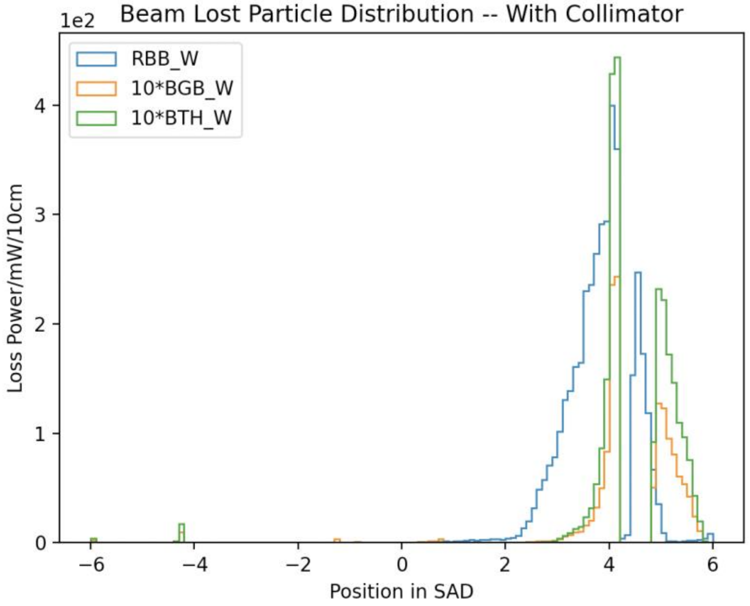
距IP距离（mm）	形状	内径(mm)	材料	内表面积(mm²)	备注	总功率&Higgs (W)	功率密度&Higgs (W/cm²)	功率分布&Higgs (W)	总功率&Z (W)	功率密度&Z (W/cm²)	功率分布&Z (W)	总功率&H Z (W)	功率密度&H Z (W/cm²)	功率分布&H Z (W)
0 – 120	圆直管	直径28	Be	10556		6.6	0. 06	6. 60	47.92	0. 45	47. 92	415.6	3. 94	415. 60
120-205	圆直管	直径28	Al	7477				2. 71			39. 44			169. 36
205-655	圆锥管	直径28过渡到直径40	Al	48071	taper:1.75	22.2	0. 04	17. 44	322.8	0. 53	253. 54	1386.3	2. 27	1088. 85
655-700	圆直管	直径40	Al	5655				2. 05			29. 83			128. 09
700-780	圆直管	直径40	Cu	10052	远程连接装置预留			2. 60			39. 05			168. 64
780-805	圆面过渡到跑道型	水平方向直径40-40，垂直方向直径40-30.7	Cu	3124		13.2	0. 03	0. 81	198.2	0. 39	12. 14	855.85	1. 68	52. 41
805-855	跑道型过渡到两个圆面	上游直径12 下游直径20	Cu	6932				1. 79			26. 93			116. 30
855-1110	上游圆锥管 下游圆直管	上游直径12过渡到20，下游直径20	Cu	30906				8. 00			120. 08			518. 50

Lost distribution

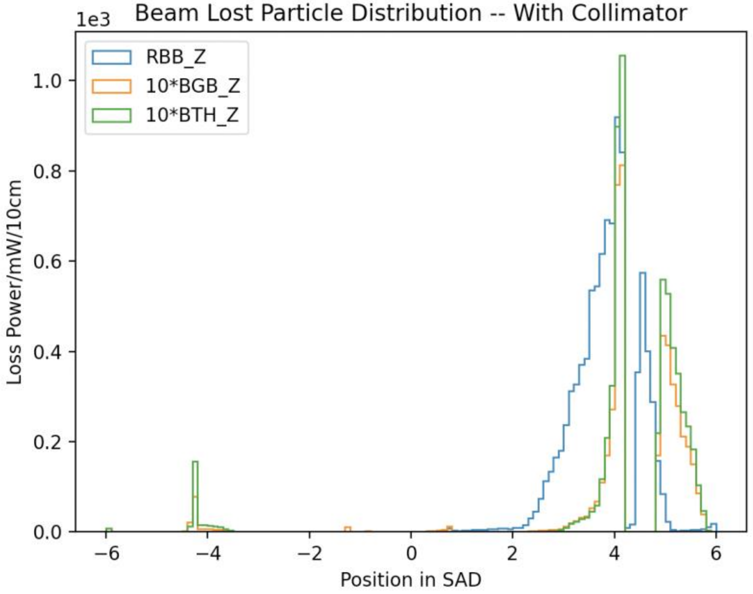
- Loss Power increases with particles number increasing.
- RBB loss is much higher than the other two.
  - Consistent with beam lifetime.



Higgs



W



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