CEPC MDI Radiation Backgrounds Study

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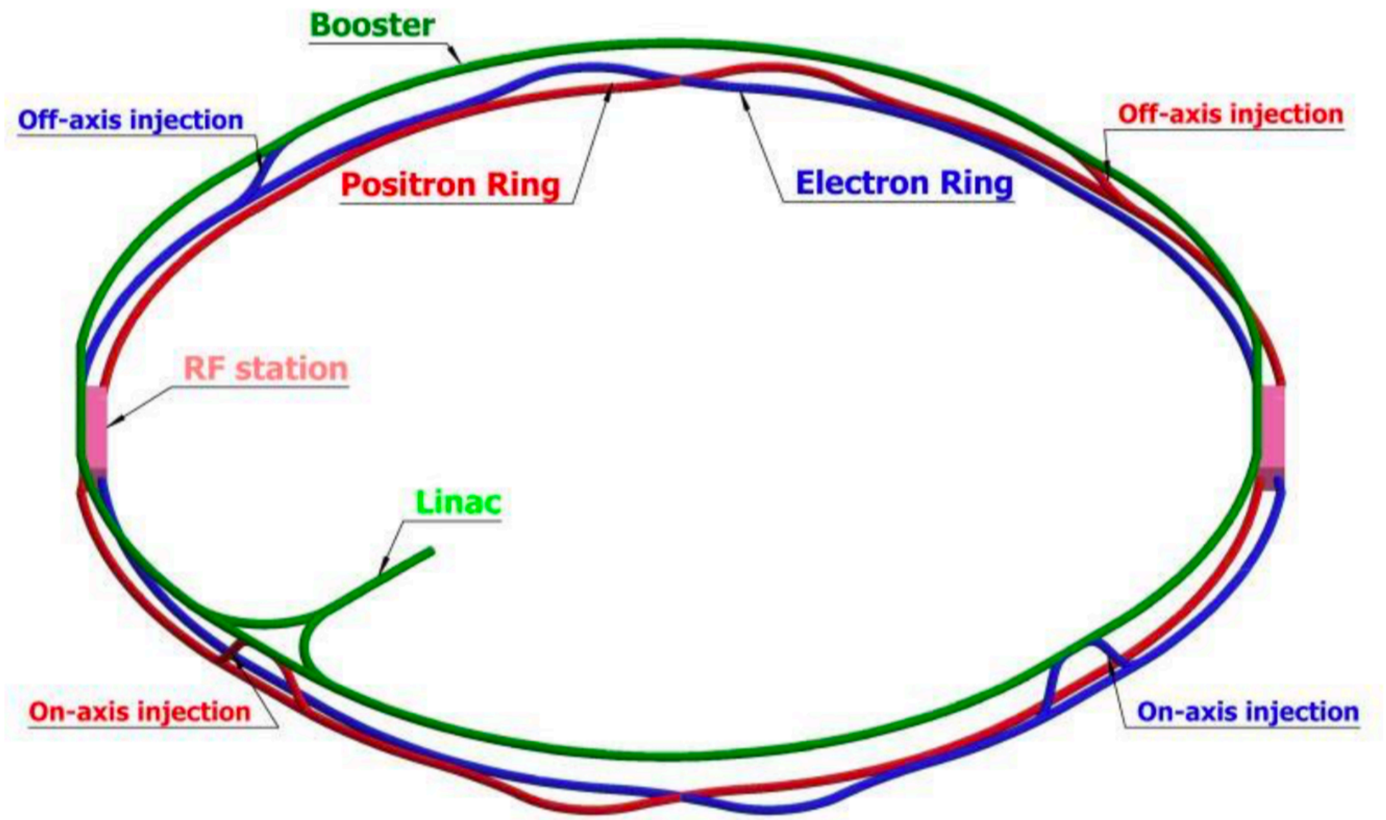
On Behalf of the CEPC MDI BG Study Group

CECP Workshop, Shanghai, 2020

Outline

- ➢Motivation & Workflow
- ➢Background Study Status in detail
- ➢Summary & Outlook



Motivation

- Backgrounds may impact IR components, especially detectors in several ways, so that they are important inputs to the detector(also accelerator) design, such as radiation tolerance, detector occupancy…

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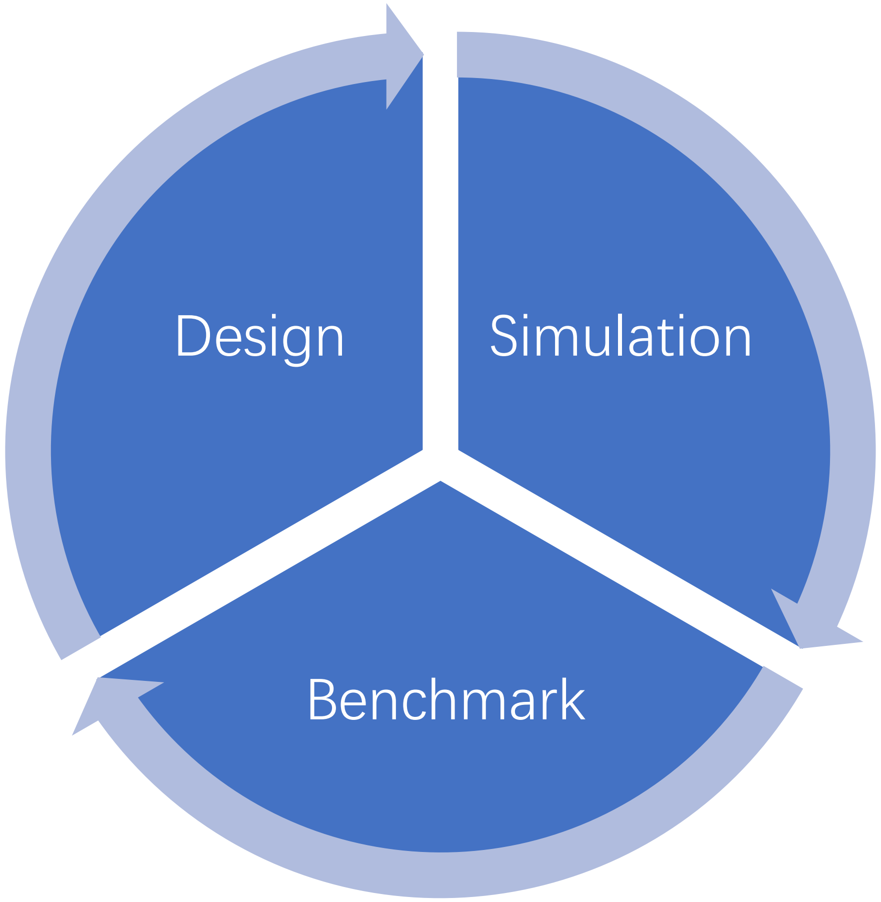
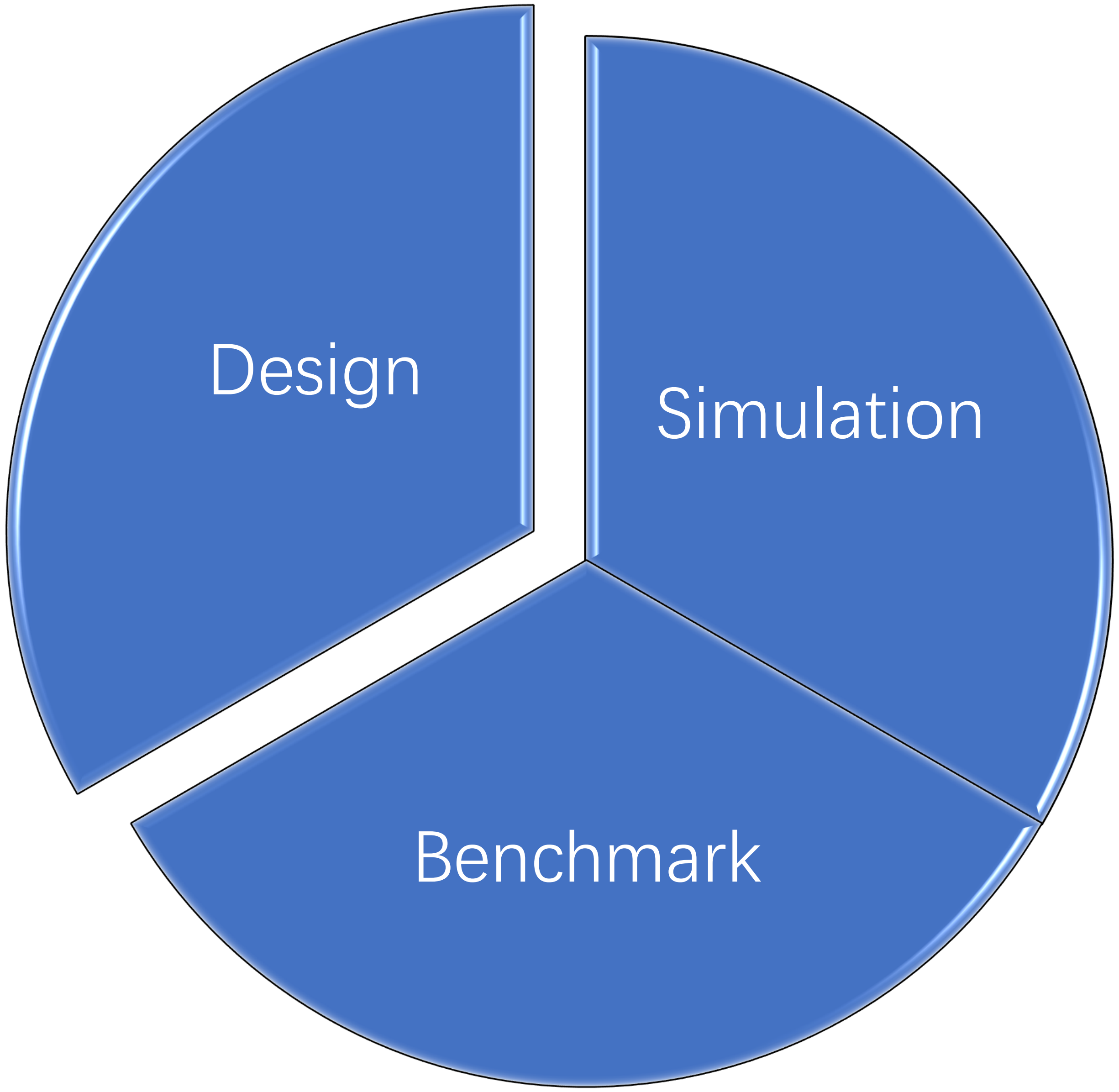


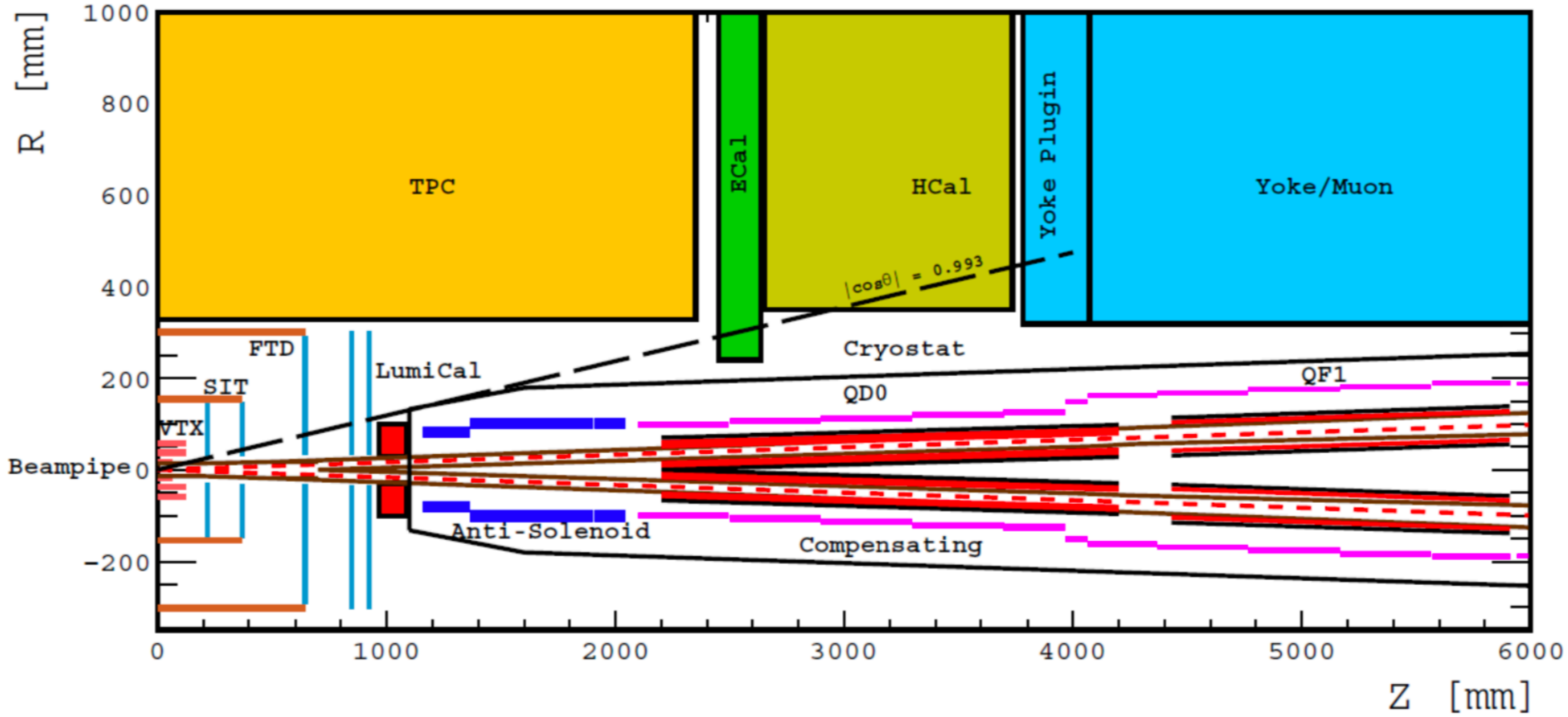
Workflow – Step 1



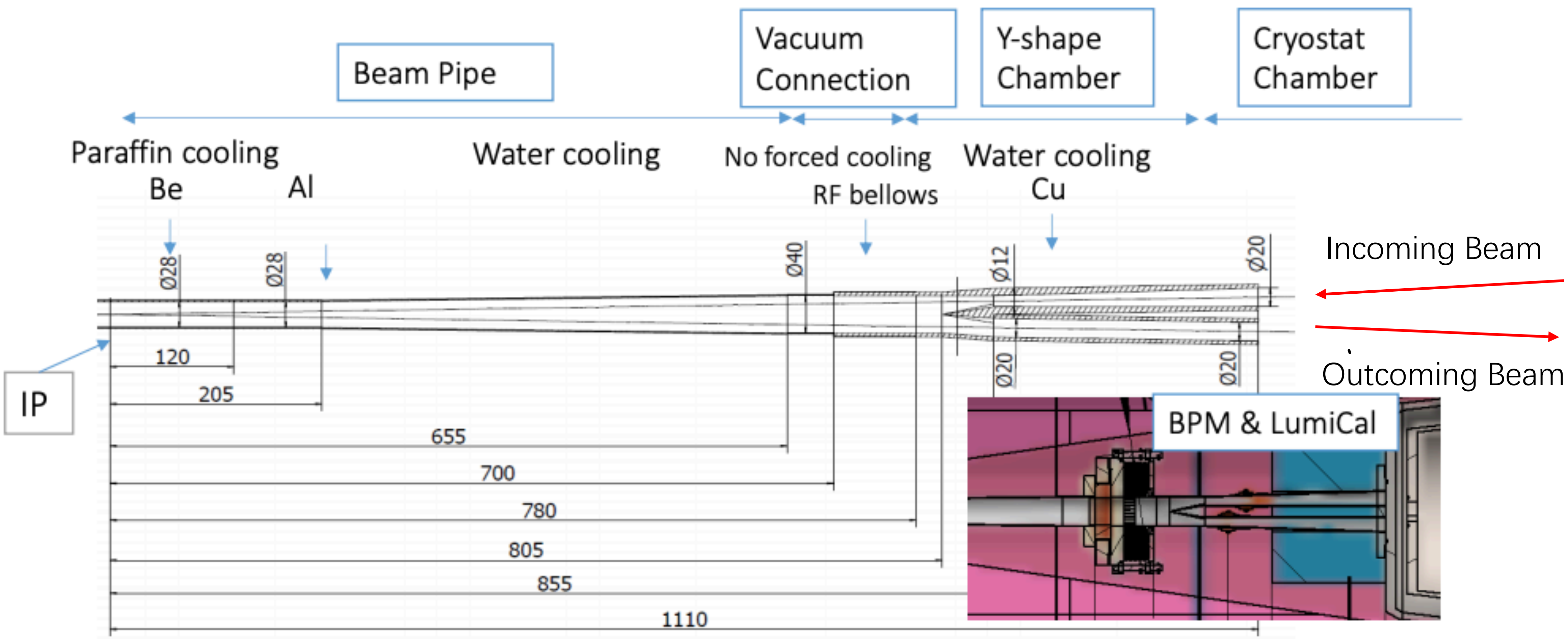
CEPC Parameters -- CDR

	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**

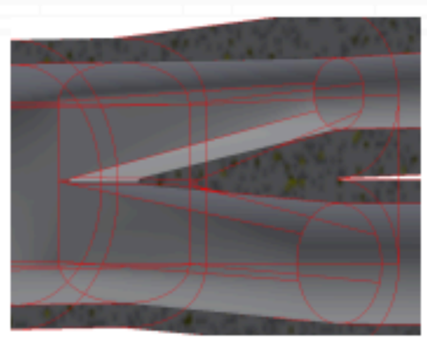
Interaction Region Layout



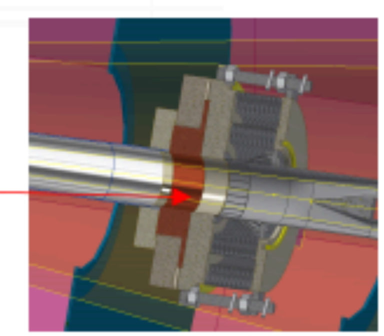
Latest design of the central beampipe



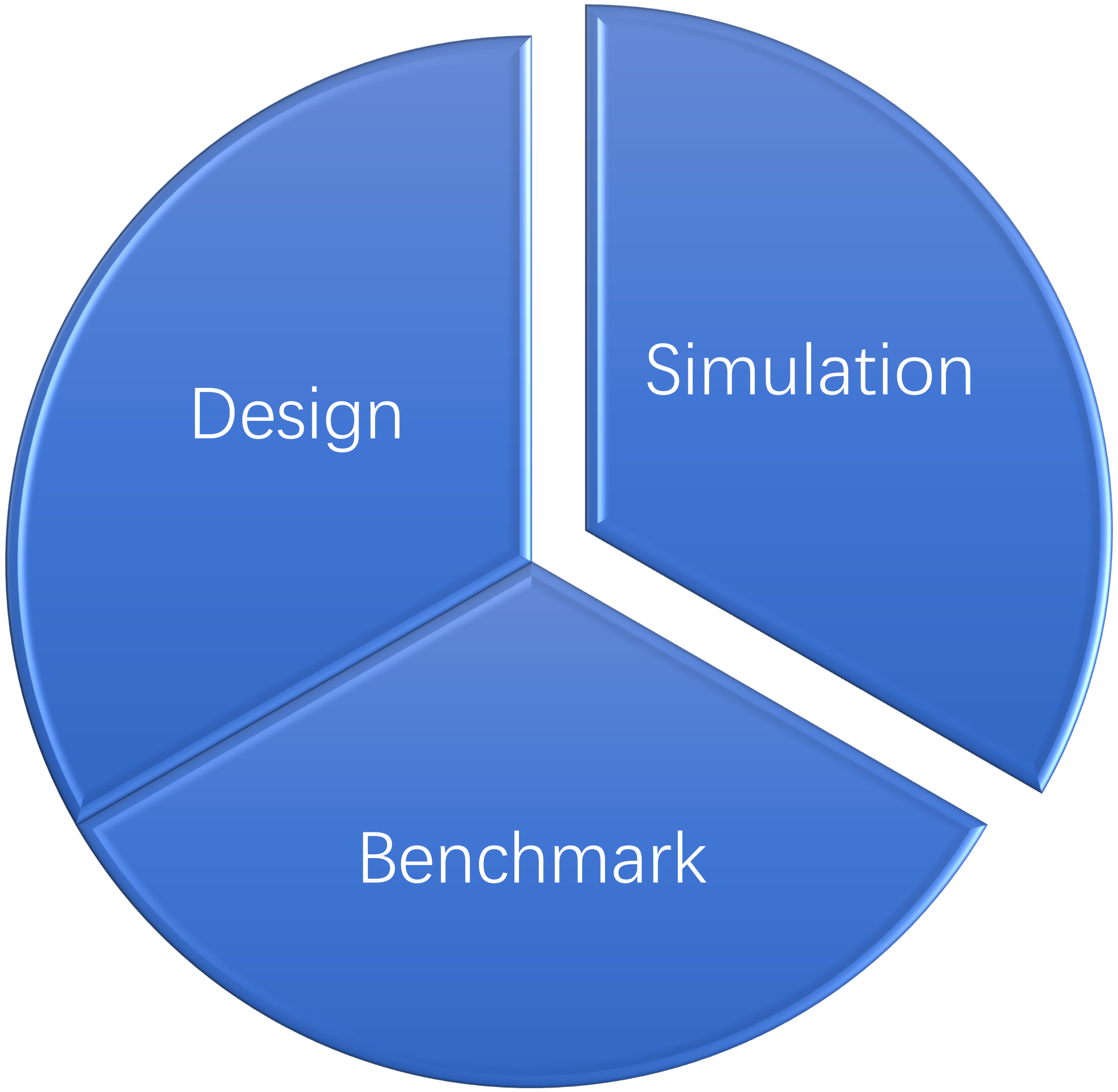
Asymmetric design to prevent direct hitting of synchrotron radiation photons



Remaining issue: difficult to dissipate the heat around the RF finger



Workflow – Step 2



Source Analysis

- Effects
  - Single Beam
    - Touschek Scattering
    - Beam Gas Scattering
    - Beam Thermal Photon Scattering
    - Synchrotron Radiation
  - Luminosity Related
    - Beamstrahlung
    - Radiative Bhabha Scattering
  - Injection

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Photons

Off Energy Beam Particles

Steps

- Steps used for one fixed Design&Parameters:

Generation
- Using the existing generators
- Building our own generators

Cross Check

Tracking
- Let the particles move alongside the pipe
- Record the lost particles within the IR

Detector Simulation
- Quantify Impacts using hit density, TID, and NIEL
- Adopted the method ATLAS used(ATL-GEN-2005-001) for background estimation

CEPC Parameters CDR - Higgs

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    - Beamstrahlung(Pair Production)
    - Radiative Bhabha Scattering

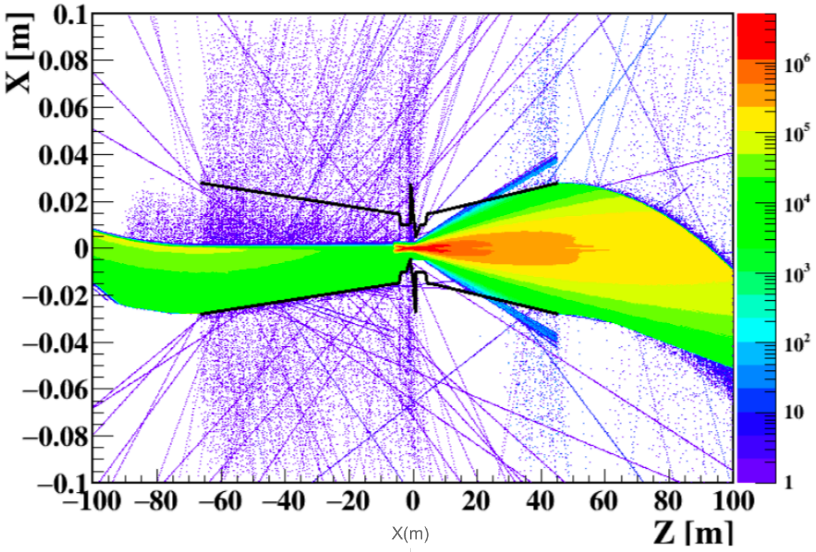
Photons

Off Energy Beam Particles

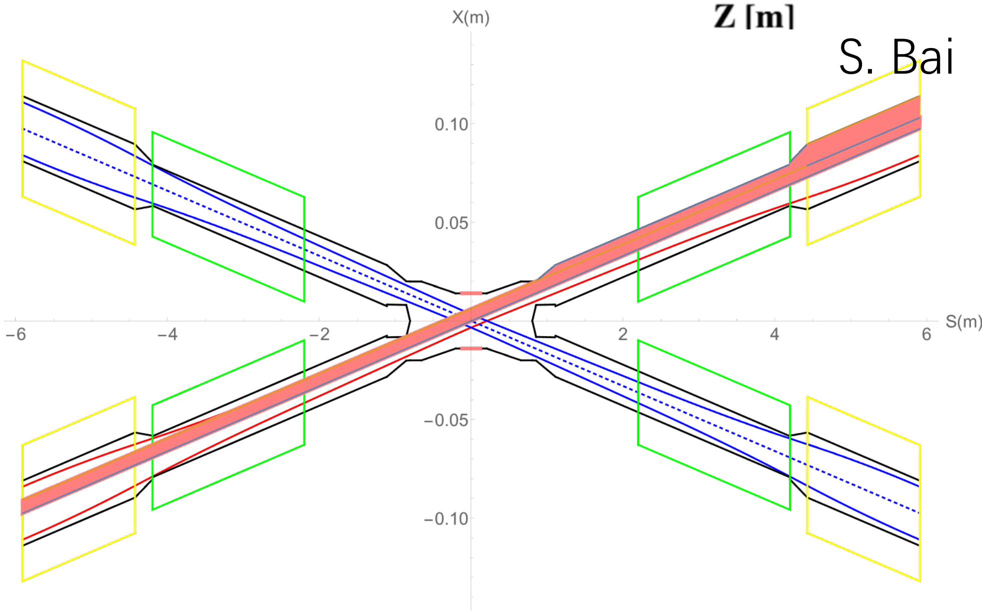
Synchrotron Radiation

- Synchrotron radiation were emitted by magnets when bending beams, sometimes would be critical at circular machines.
- Using BDsim&Geant4 as the tool to transport beam particles from the last dipole to the interaction region and record the photons hitting the central beryllium pipe.
- The newly designed central beam pipe will let SR pass -855mm~855mm even with the error of (5mm+2mrad).
- Some SR photons may hit the beampipe, and scattered into central beam pipe.
    - Masks might be needed.

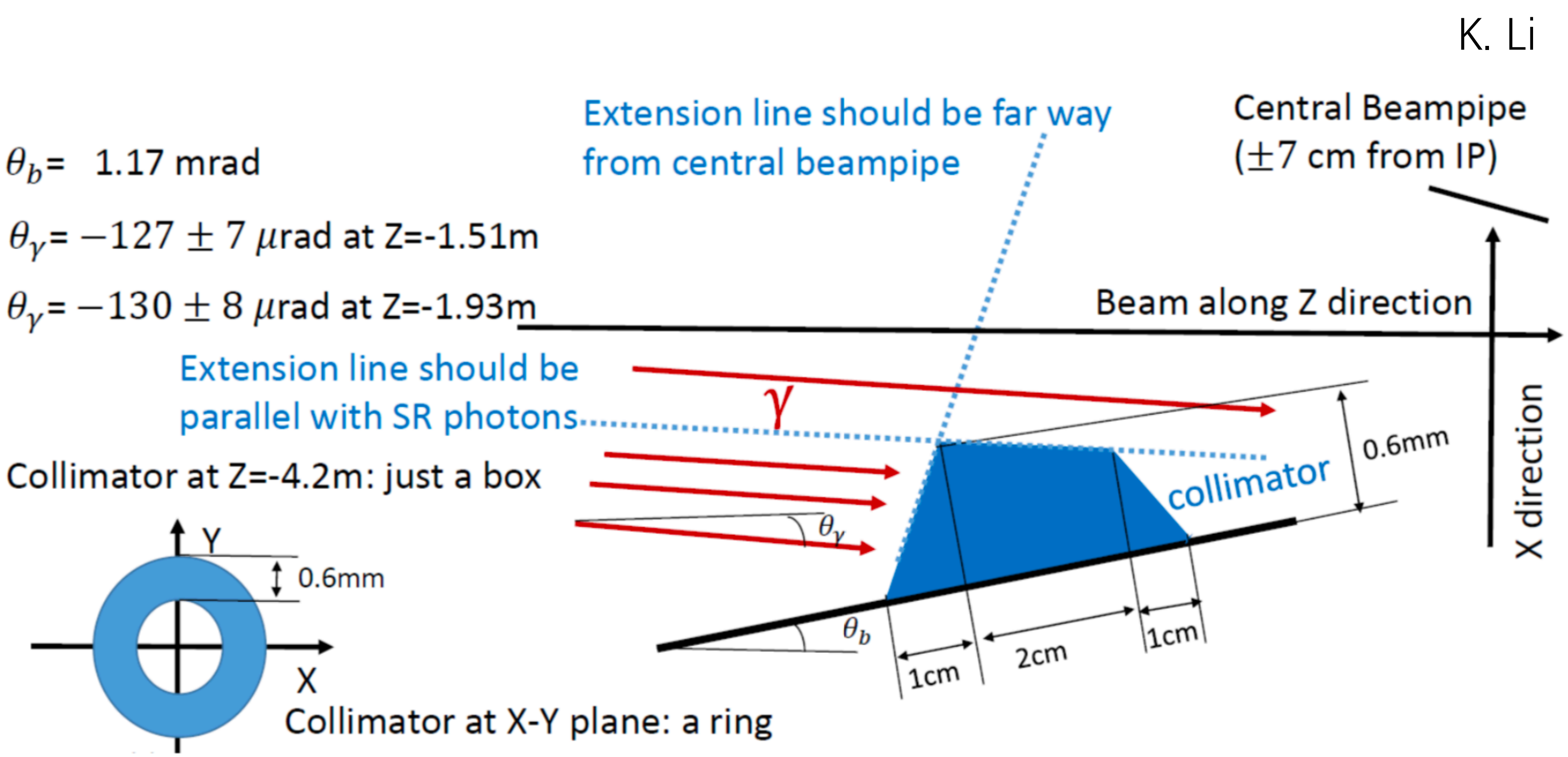
K. Li



S. Bai



SR Mask



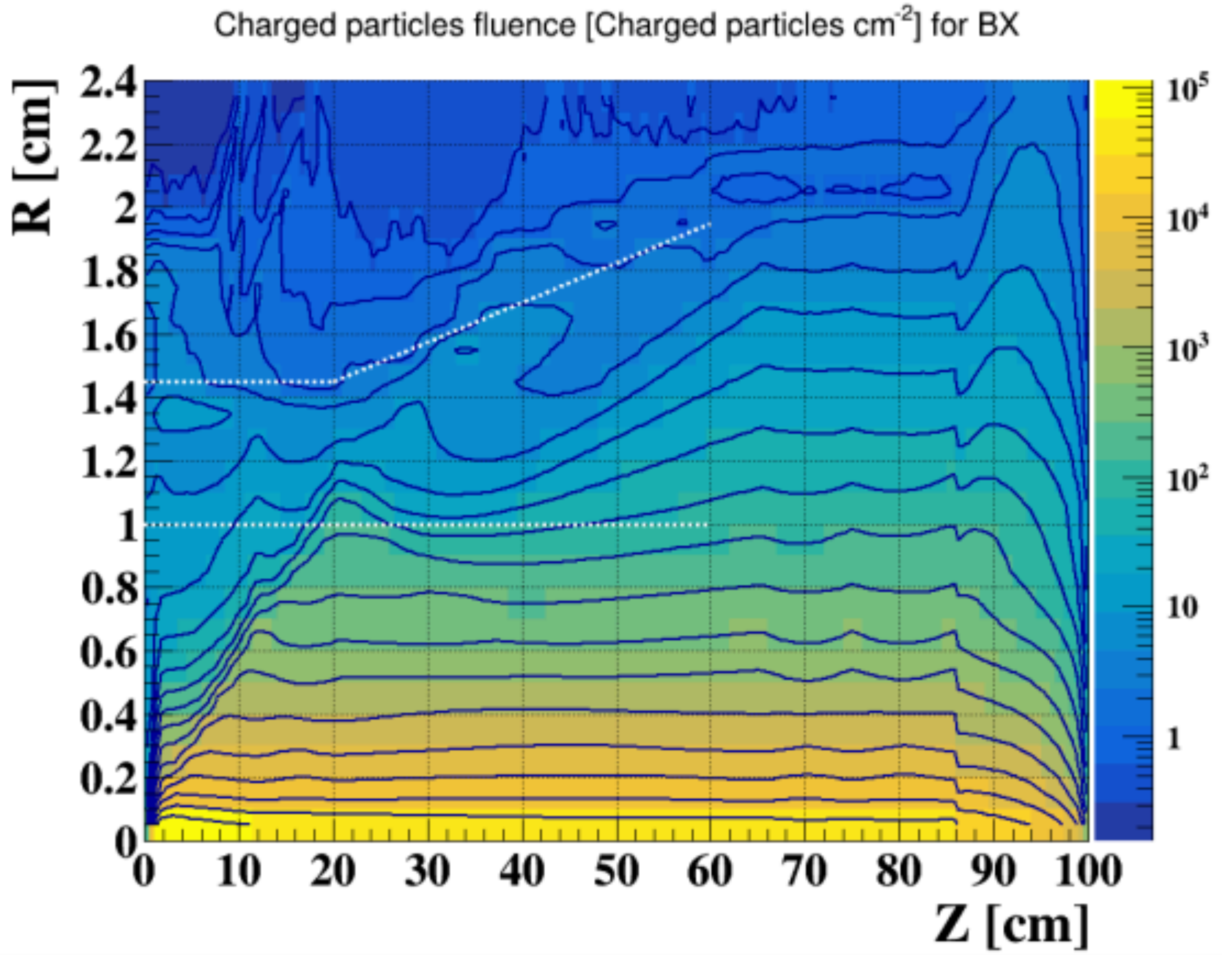
- This is the original SR Mask design based on the original design.
- We need update the design to fit the new demands.

Detector hit numbers down from 7.73*10^4 to 111 per bunch.
TID down from ~5800 kRad/yr to 15.65 kRad/yr

Pair Production

- Charged Particles attract by the opposite beam emit photons(beamstrahlung), followed by an electron-positron pair production.
- Using Guinea-pig++ as the generator and implementing the external magnetic field by code updating.

W. Xu



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Photons

Off Energy Beam Particles

CEPC Beam Lifetime

	Beam Lifetime	Others
Touschek effect	>1000 h	
Beam Gas Coulomb	>400 h	CO, 10^{-7} Pa
Beam Gas Bremsstrahlung	63.8 h	CO, 10^{-7} Pa
Beam Thermal Photon Scattering	50.7 h	
Radiative bhabha Scattering	74 min	
Beamstrahlung	80 min	

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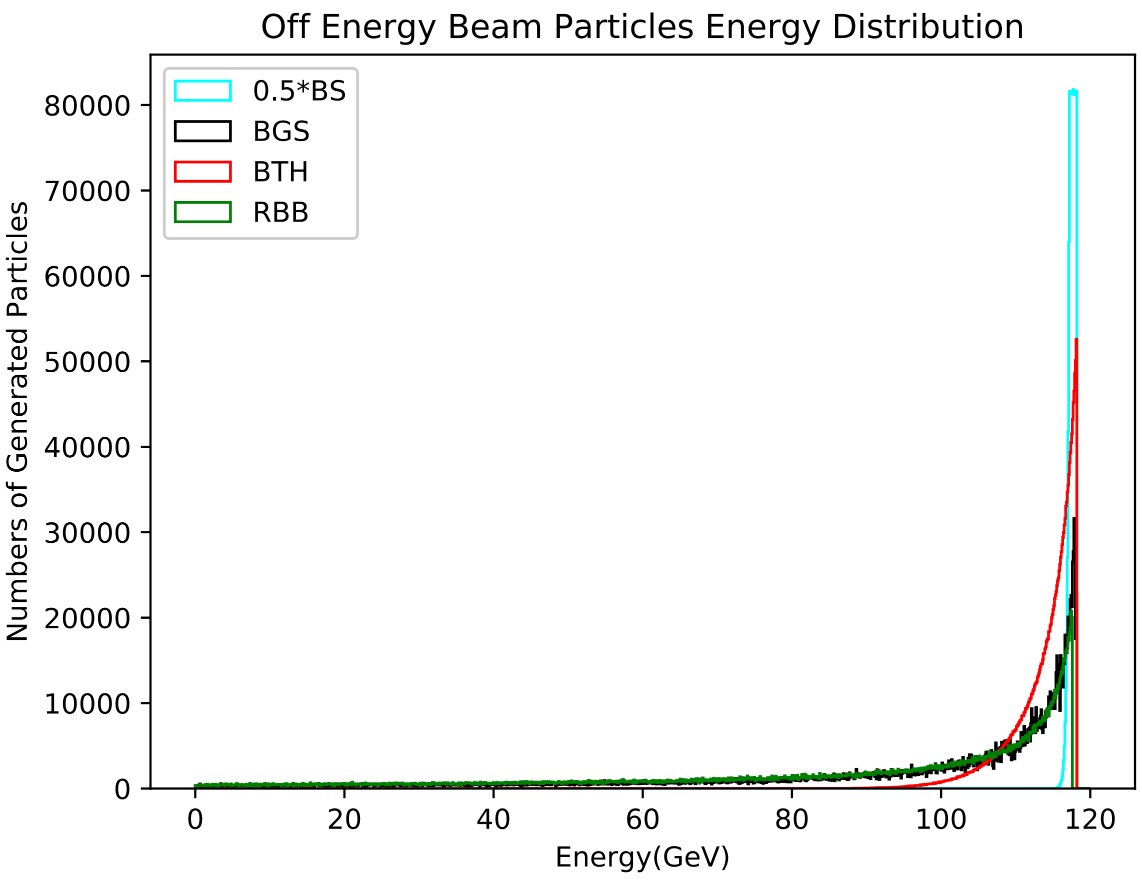
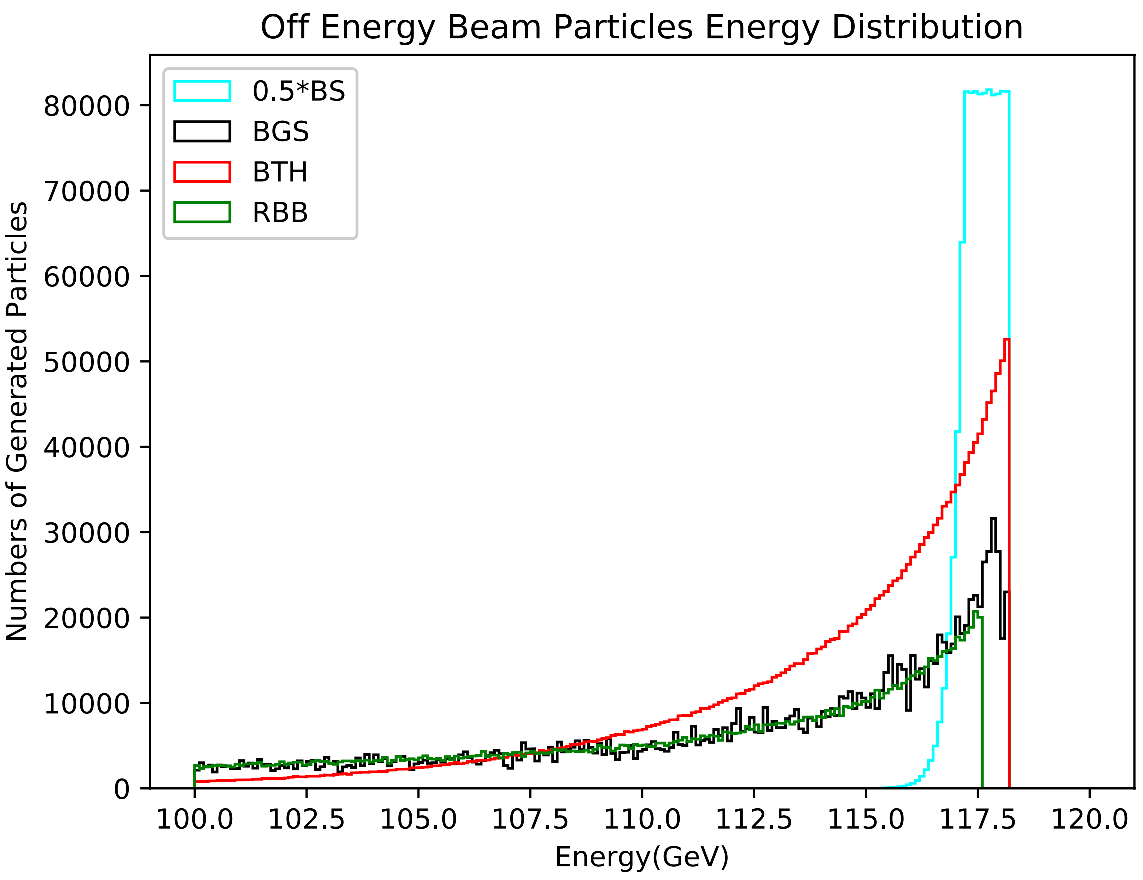
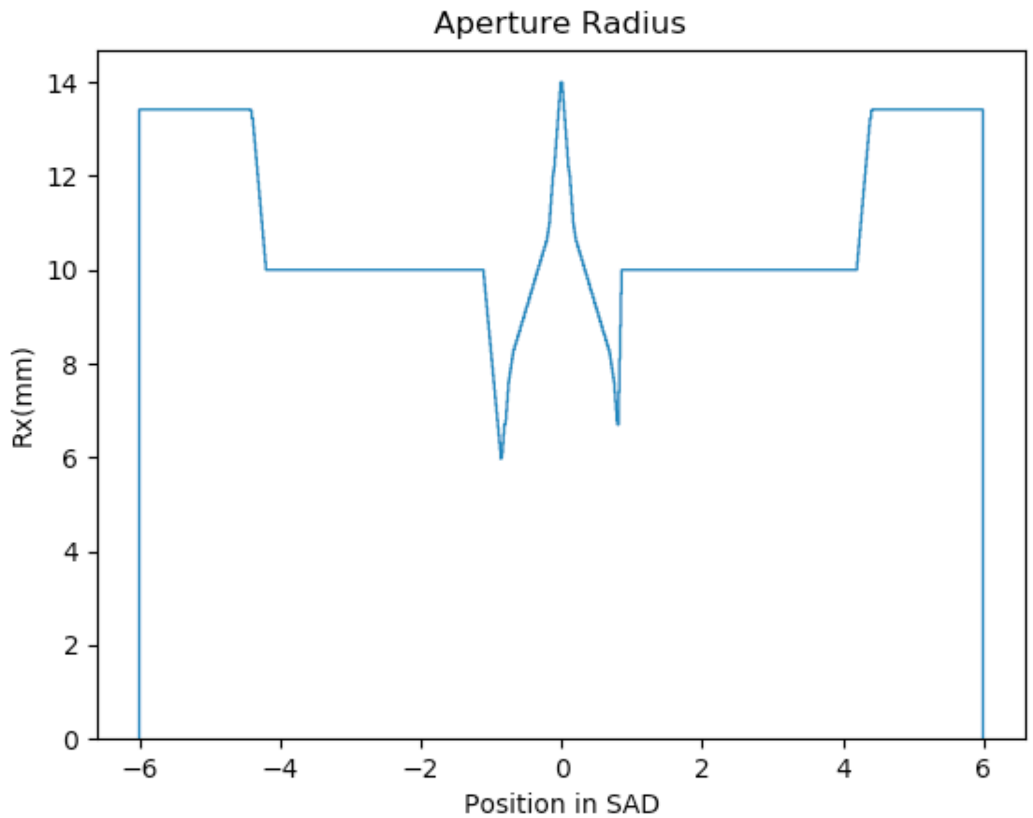
Energy Spectrum





Update of the Tracking Method

- 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.

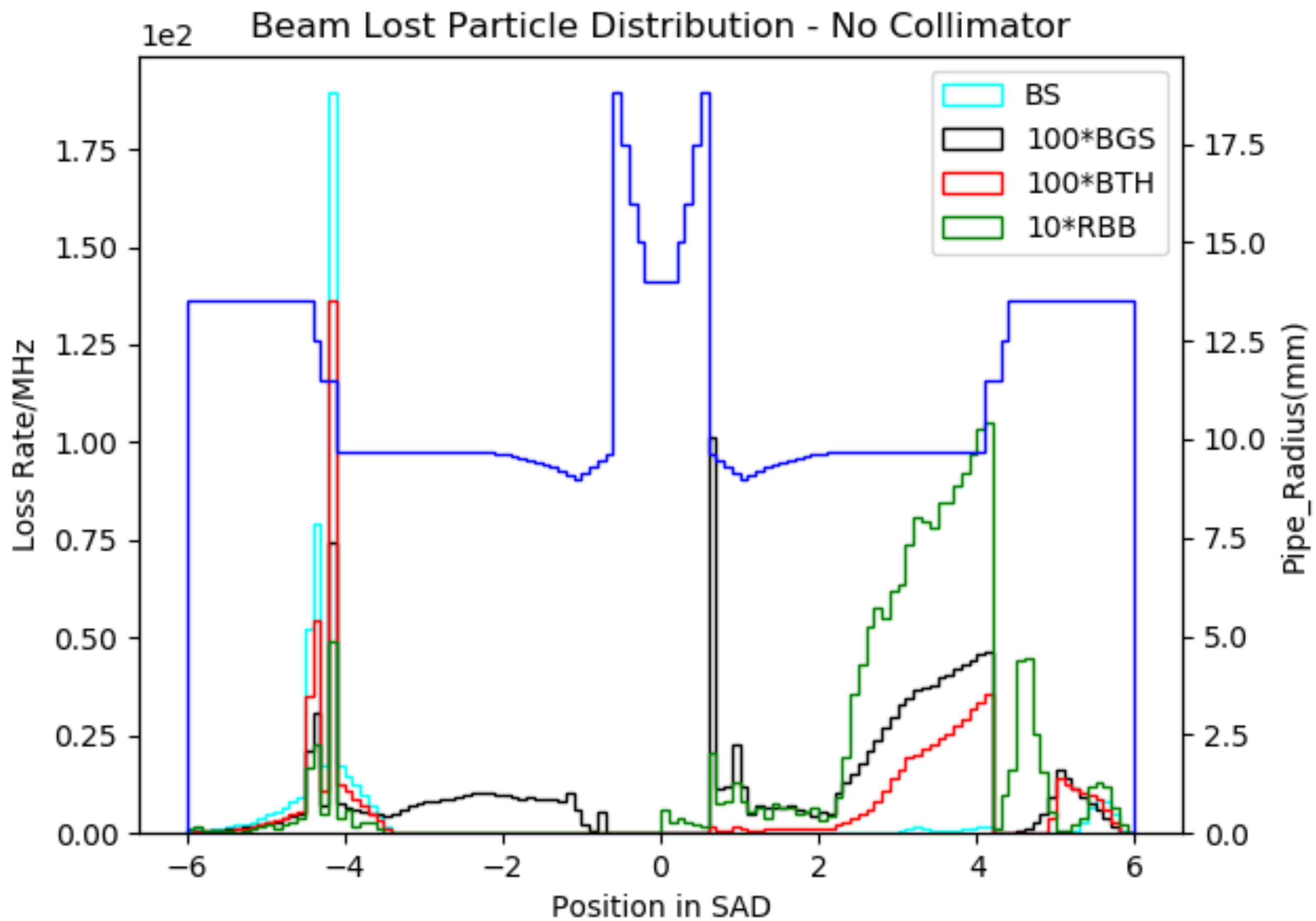


- Then we track the scattered particles for 50 turns, using the SAD built-in TrackParticle function with LOSSMAP, FLUC, RFSW & RAD ON(SAD Version 1.1.6.16.3k64).
- Updating code to output the particle position at the beginning of(rather than at the end of) the lost components, then let Mokka handle the "last step tracking" and the interaction.

Lost Distribution without Collimators

- 4 types of Backgrounds
- Normalized to loss rate in MHz(one beam)
- BS contributes the most

Old Tracking Method



Collimator

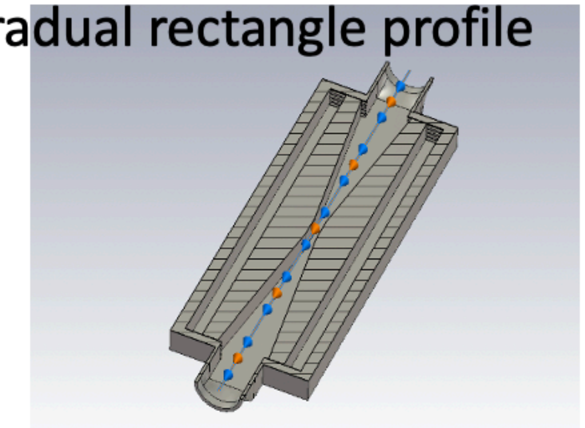
- Collimators are need.
- Now we put 2 sets of horizontal collimators.
- We only take primary into consideration.
- In higgs mode, the radius of the aperture is 5mm(Z is 2.5).

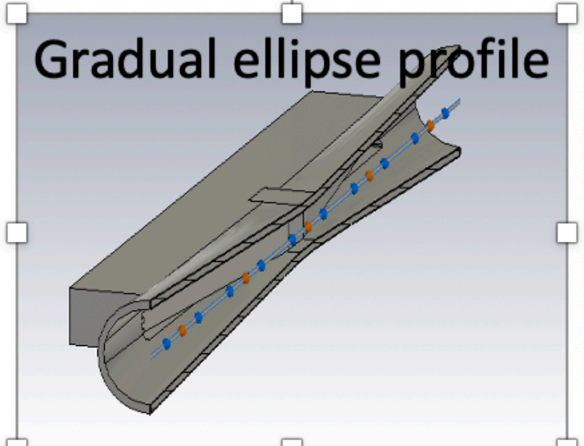
S. Bai

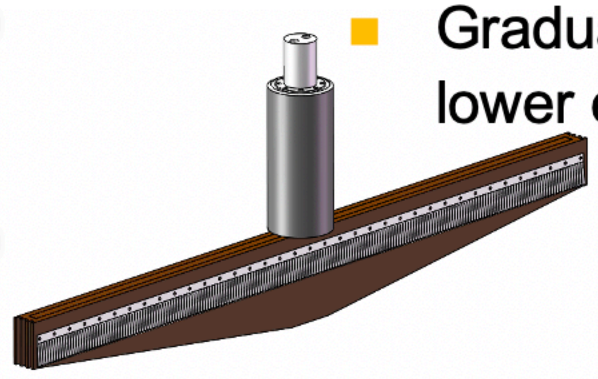
Name	Location	Distance to IP
APTX1	D1I.1897	2139.06
APTX2	D1I.1894	2207.63
APTX3	D1O.10	1832.52
APTX4	D1O.14	1901.09

Collimator

H. Wang

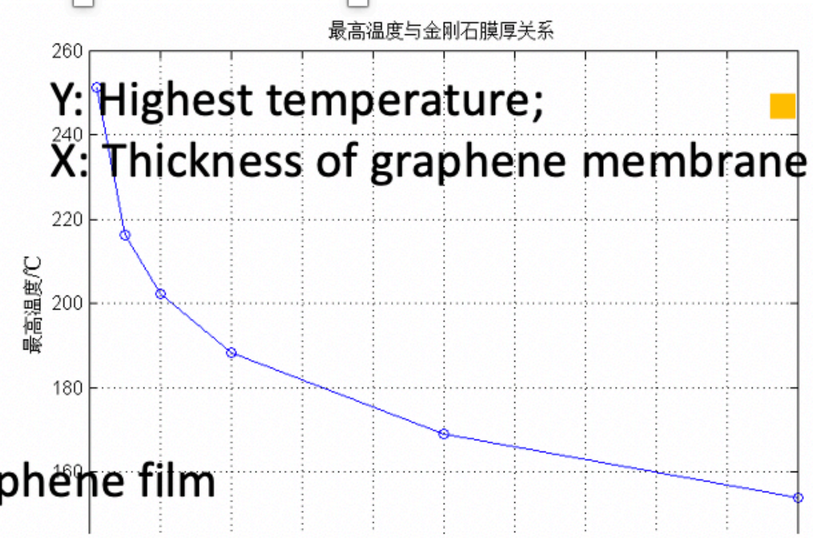






- Gradual ellipse has lower energy loss.

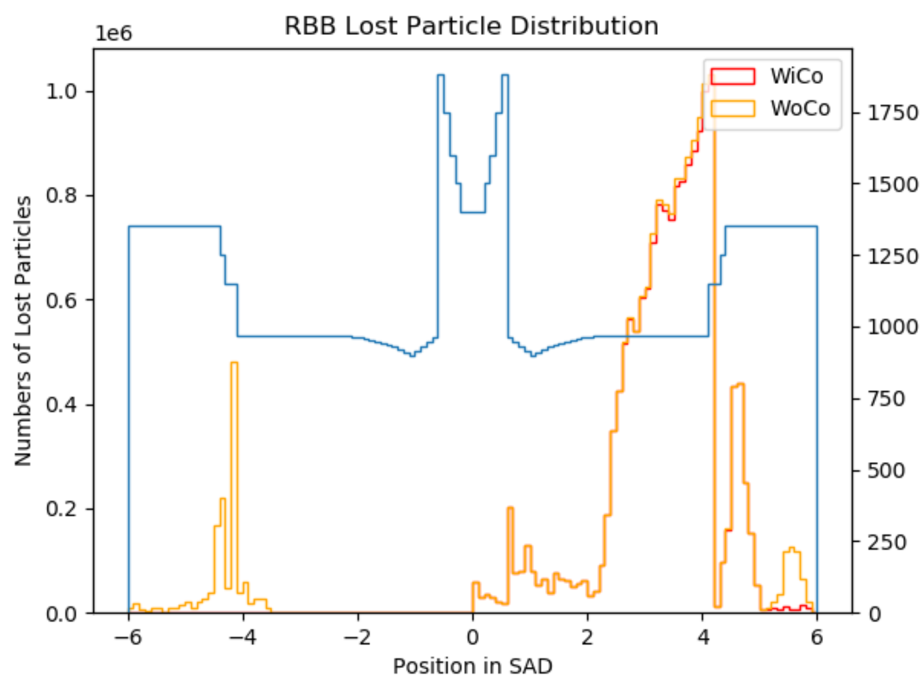
Laminated material with copper and graphene film

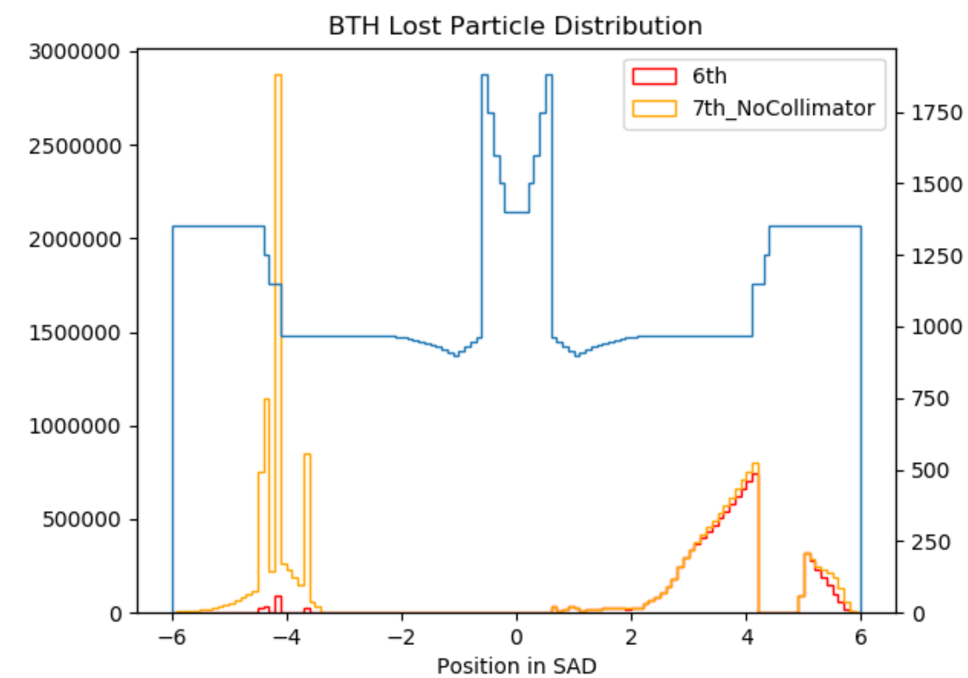


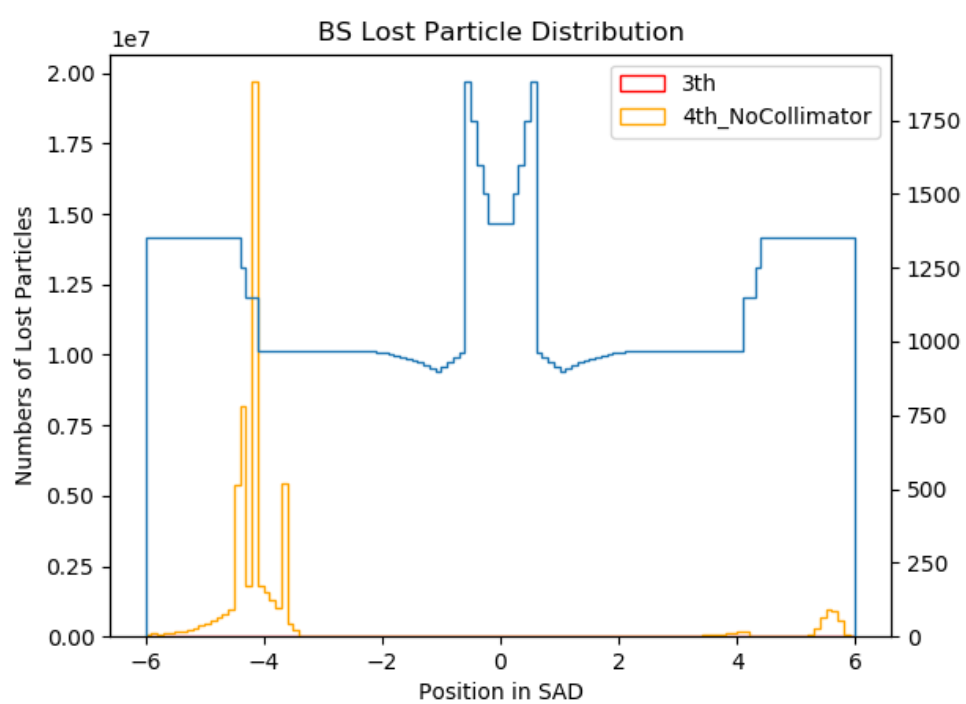
- Graphene film is a candidate material for thermal dissipation.

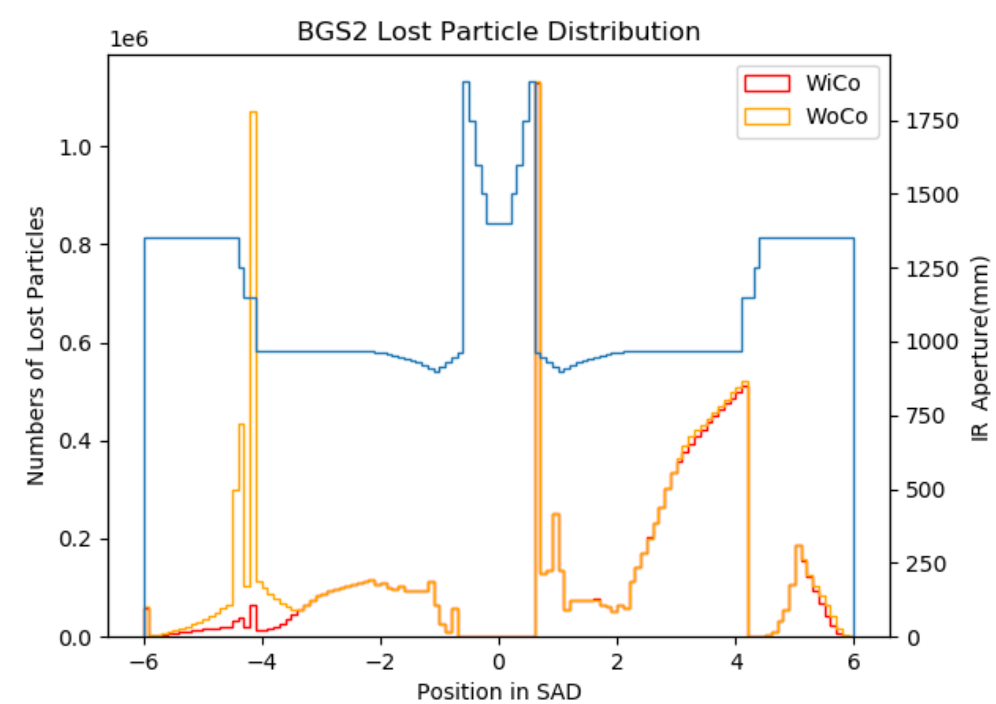
- In simulation, we thought the collimators were "perfect”
- More collimators are sure to be needed, we should start study.

Collimator Effects



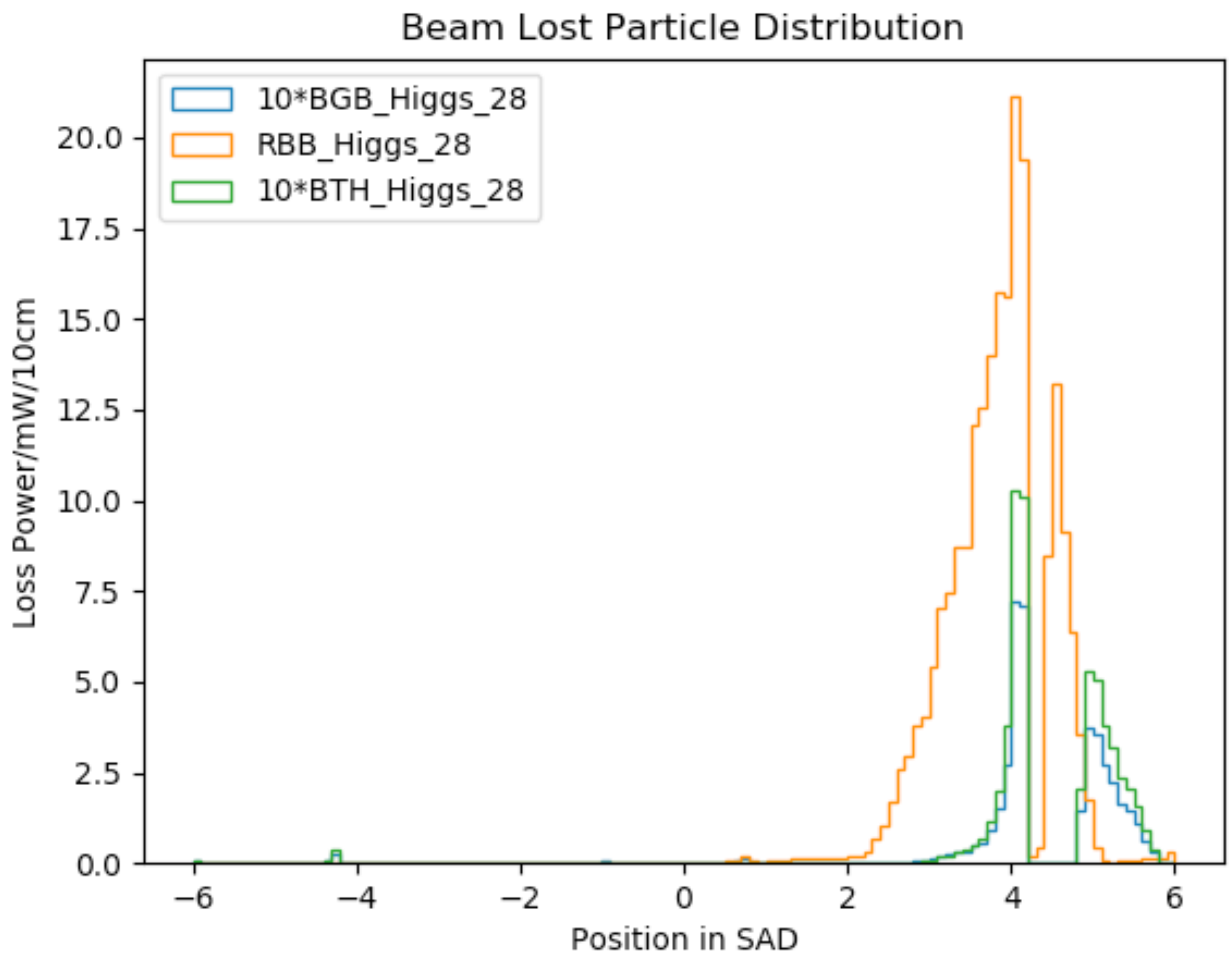






Lost Distribution with Collimators(Higgs)

- Including Radiative Bhabha, Beam-Gas, Beam Thermal Photon. Almost No Beamstrahlung.
- Normalized to loss power in mW(one beam)



Combine Results

Higgs Backgrounds on 1st layer of Vertex.
With a safety factor of 10.

Background Type	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)	1 MeV equivalent neutron fluence ($n_{eq} \cdot cm^{-2} \cdot yr^{-1}$)
Pair production	1.91	526.11	1.05×10^{12}
Synchrotron Radiation	0.026	15.65	
Radiative Bhabha	0.34	592.66	1.44×10^{12}
Beam Gas	0.9607	1235.9	3.37×10^{12}
Beam Thermal Photon	0.02	22.31	6.20×10^{10}
Total	3.2567	2392.63	5.922×10^{12}

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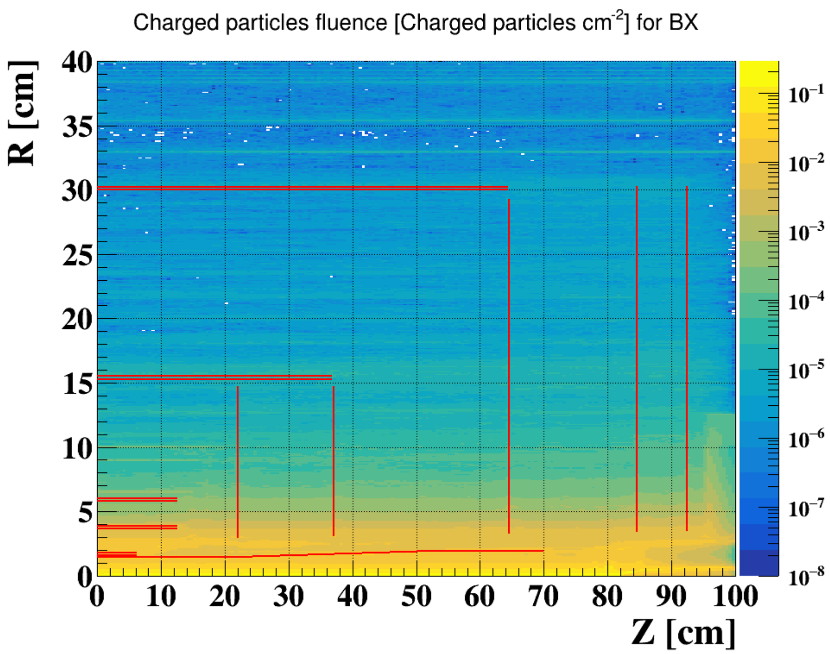
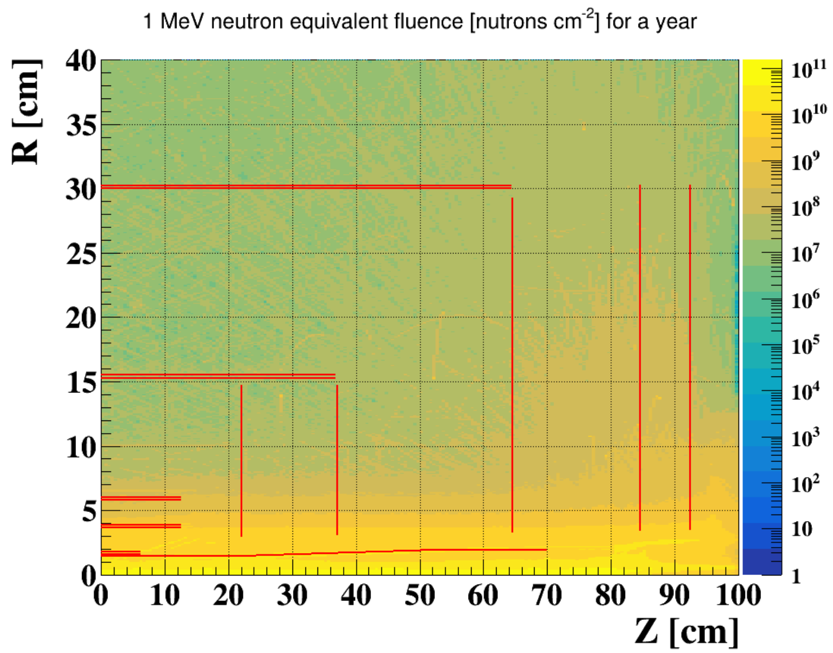
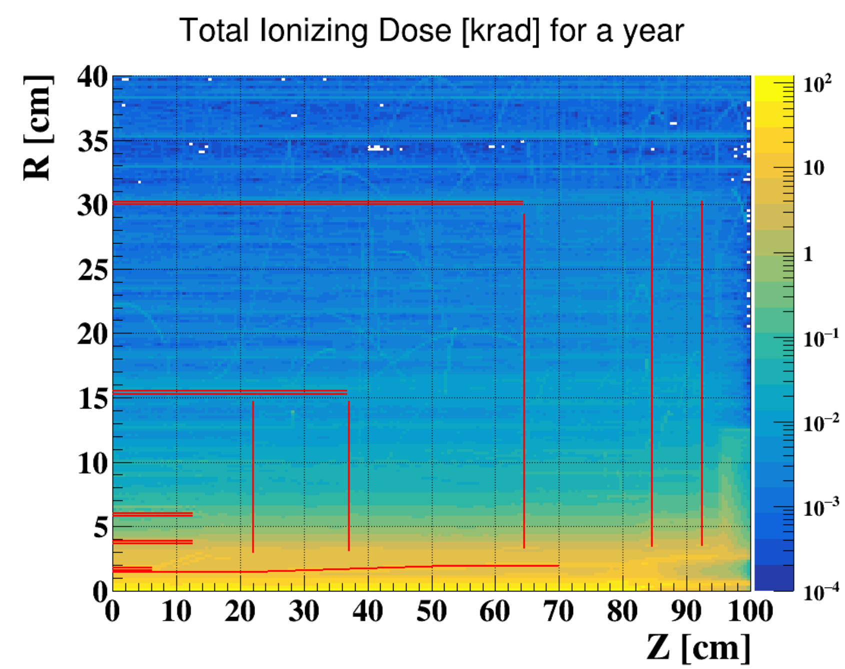
Initial results of detector impact on Z







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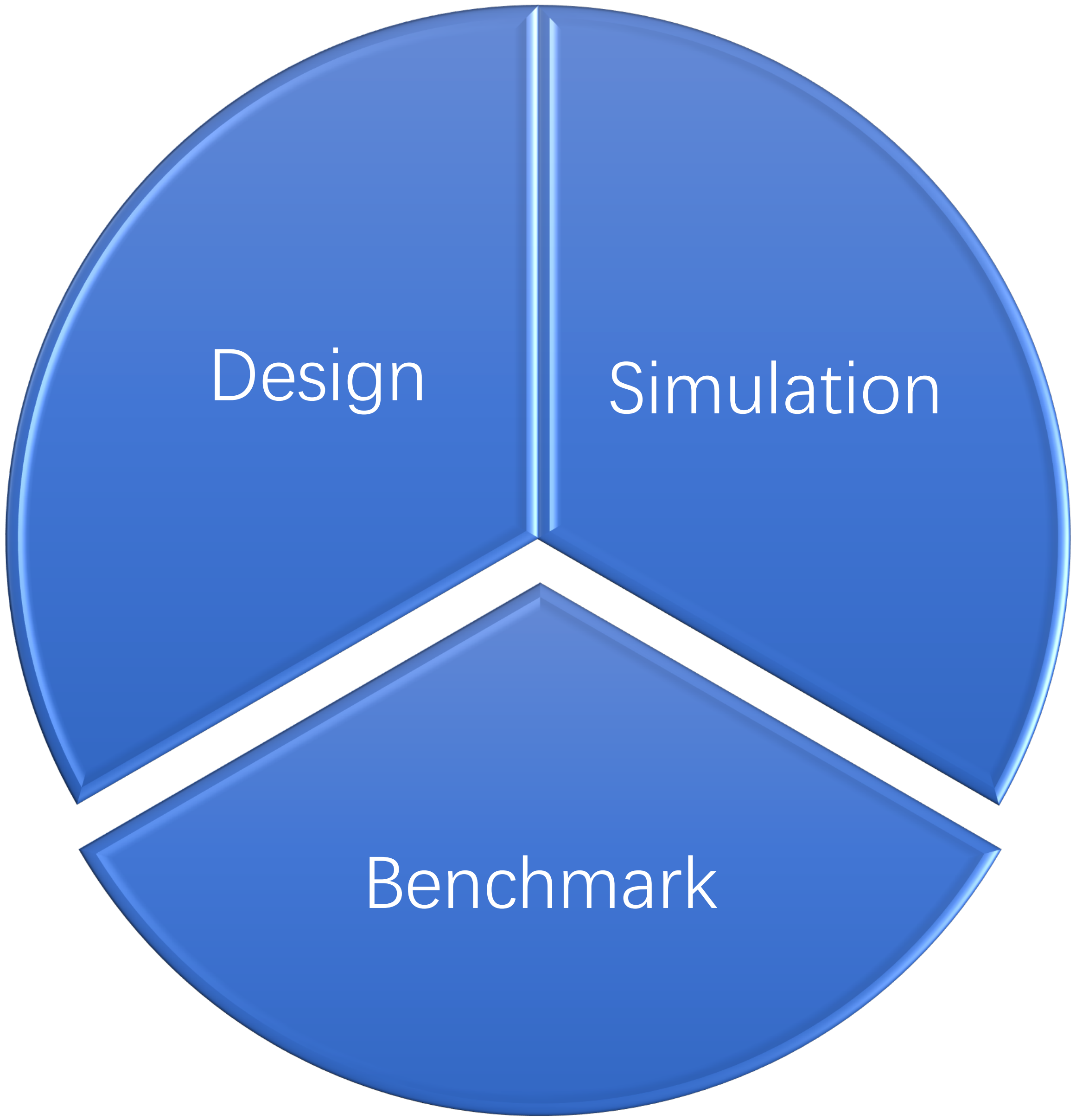
Pair production	0.012	239.59	4.50×10^{11}
Beam Gas	2.89×10^{-3}	181.97	4.99×10^{11}

Workflow – Step 3



Experiments - Benchmark

- 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
  - 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
  - $O_{total} = O_{e^+} + O_{e^-} + O_{\mathcal{L}}$

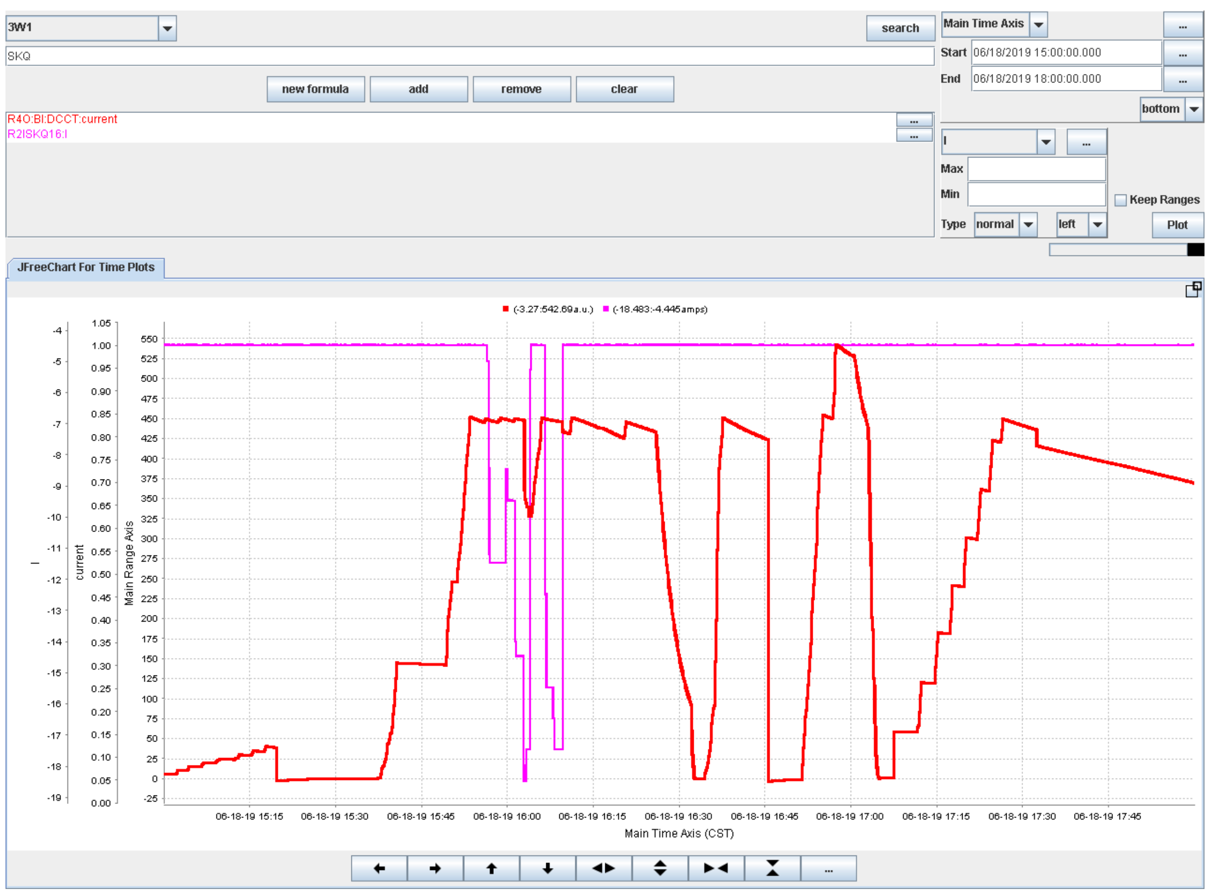
Experiments - Benchmark

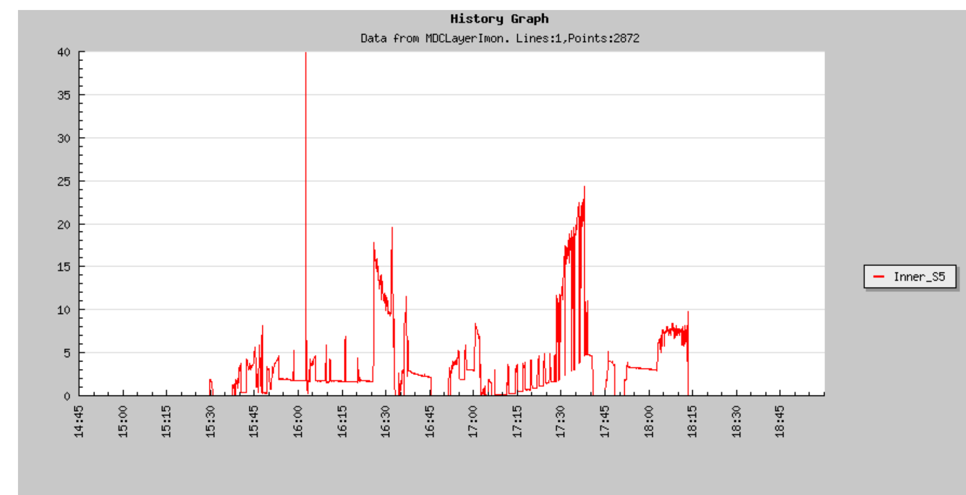
$$O = S_t \cdot D(\sigma_{x'}) \cdot \frac{I_t \cdot I_b}{\sigma_x \sigma_y \sigma_z} + S_g \cdot I_t \cdot P(I_t) + S_e$$

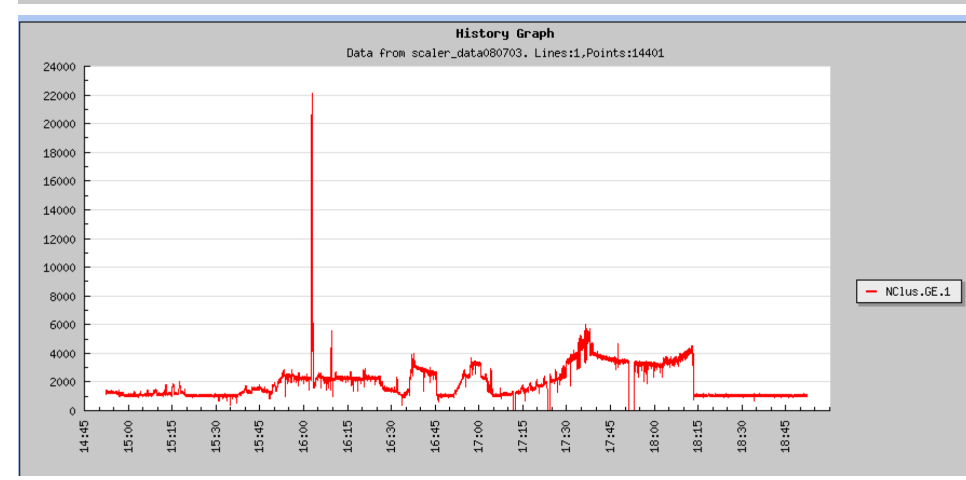
- No Beam, Measure noise: S_e
- Single Beam Mode(e-):
  - Touschek backgrounds: with fixed beam energy and beam total current(I_t), varying bunch number(changing I_b), bunch size(σ_y) -> S_t
  - Beam-gas backgrounds: with bunch current and bunch size fixed, increasing the bunch number
- Double Beam Mode:
  - Measure background in e+ with fixed parameters(only one point)
  - Colliding e+ and e- beams

Machine Studies Last Summer

- Two hours of machine time allocated to background studies last summer.
- Recorded parameters: bunch size, beam current, beam lifetime, vacuum pressure, MDC/EMC cluster counts.

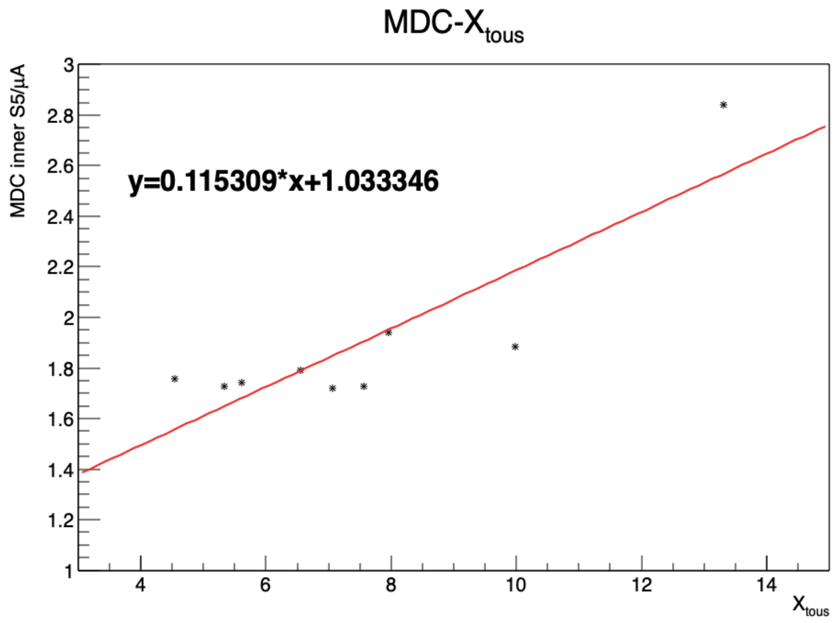


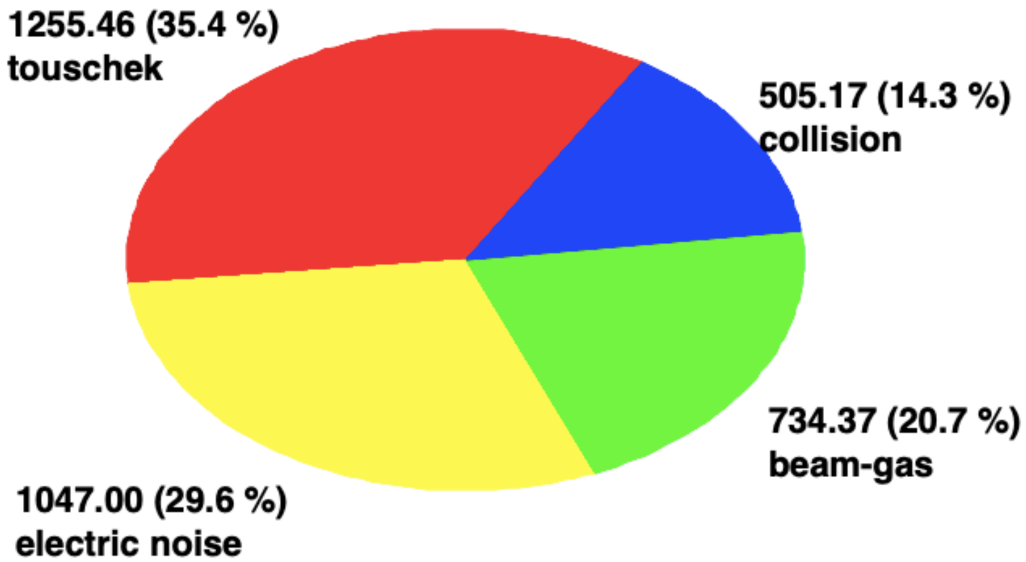




We may need one more round

- Simulations results DO NOT match the measurements





- Let the accelerator and detector configured properly before study
- Most importantly, longer time, more data.

Summary

- Background Study Checklist

Category	Tasks	Status
Design	IR Design Optimization	To Do
	Collimator Design	Doing
Simulation	BG Simulation	Doing
	Collimator Simulation	To Do
	Detector Simulation	Doing
	IR Components Simulation	To Do
Benchmark	BEPCII/BESIII Machine Study	To Do
	Literature Benchmark	Doing

Summary & Outlook

- Detector beam background would effect the component located in the interaction region through several ways.
- It must be well studied starting from the design phase.
- We need to mitigate the impact by adding some masks and collimators or other ways. They must be well designed.
- Extra-shielding may be needed. The designing of it should be started.
- We almost finished the study based on original CDR, and may update the simulation with the new design and new parameters.

Thank You

Back up

Shrink the central beampipe to 20mm

ver3.1 20200917 d20−d40−d20接口700−上游锥管下游直管						
距IP距离	内壁尺寸（mm）	材料	内面积mm^2	备注		
0−85	直径20	Be	53406		探测器部分	
85−130	直径20	Al	2827			
130−655	直径20过渡到直径40	Al	49489			
655−700	直径40	Al	5655			
700−780	直径40	Cu	10052	远程连接装置预留	加速器部分	
780−805	直径40过渡到30.7−40跑道型。水平方向40−40，垂直方向40−30.7	Cu	3124			
805−855	分叉，跑道型过渡到两个圆面，直径分别为上游12，下游20	Cu	6932			
855−1110	上游圆锥管，直径12过渡到20。下游直径20直管	Cu	30906