CEPC MDI Beam Backgrounds Study

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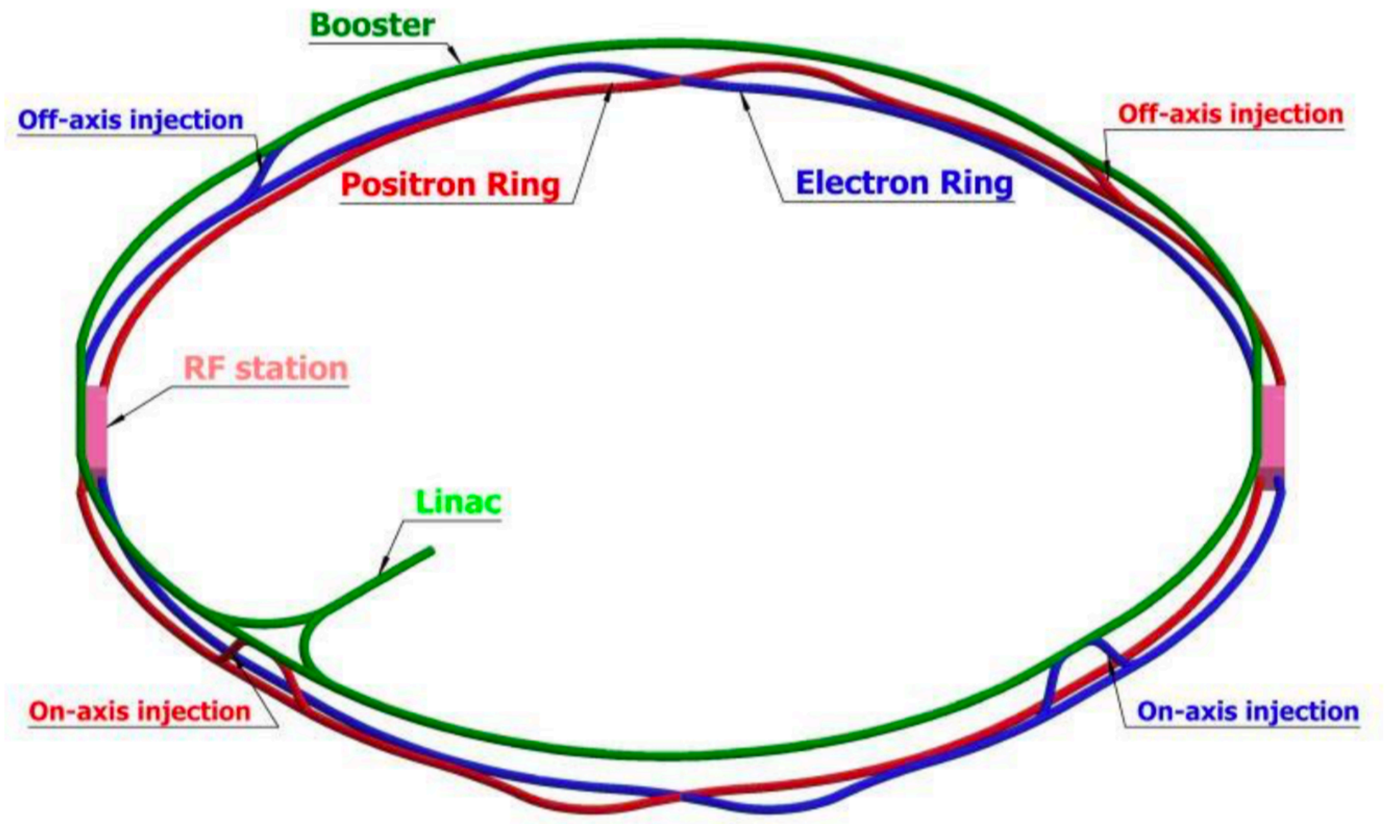
IHEP
On Behalf of the CEPC MDI BG Study Group

CECP MDI Workshop, Online, 2020

Outline

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



Motivation & Workflow

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

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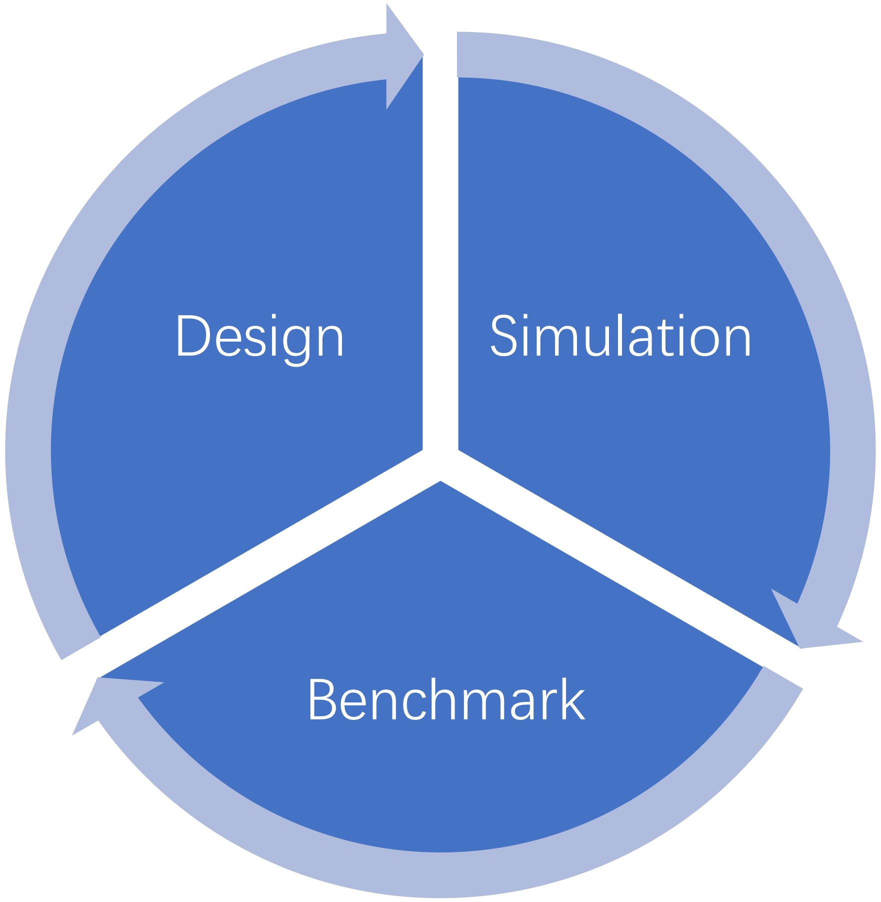
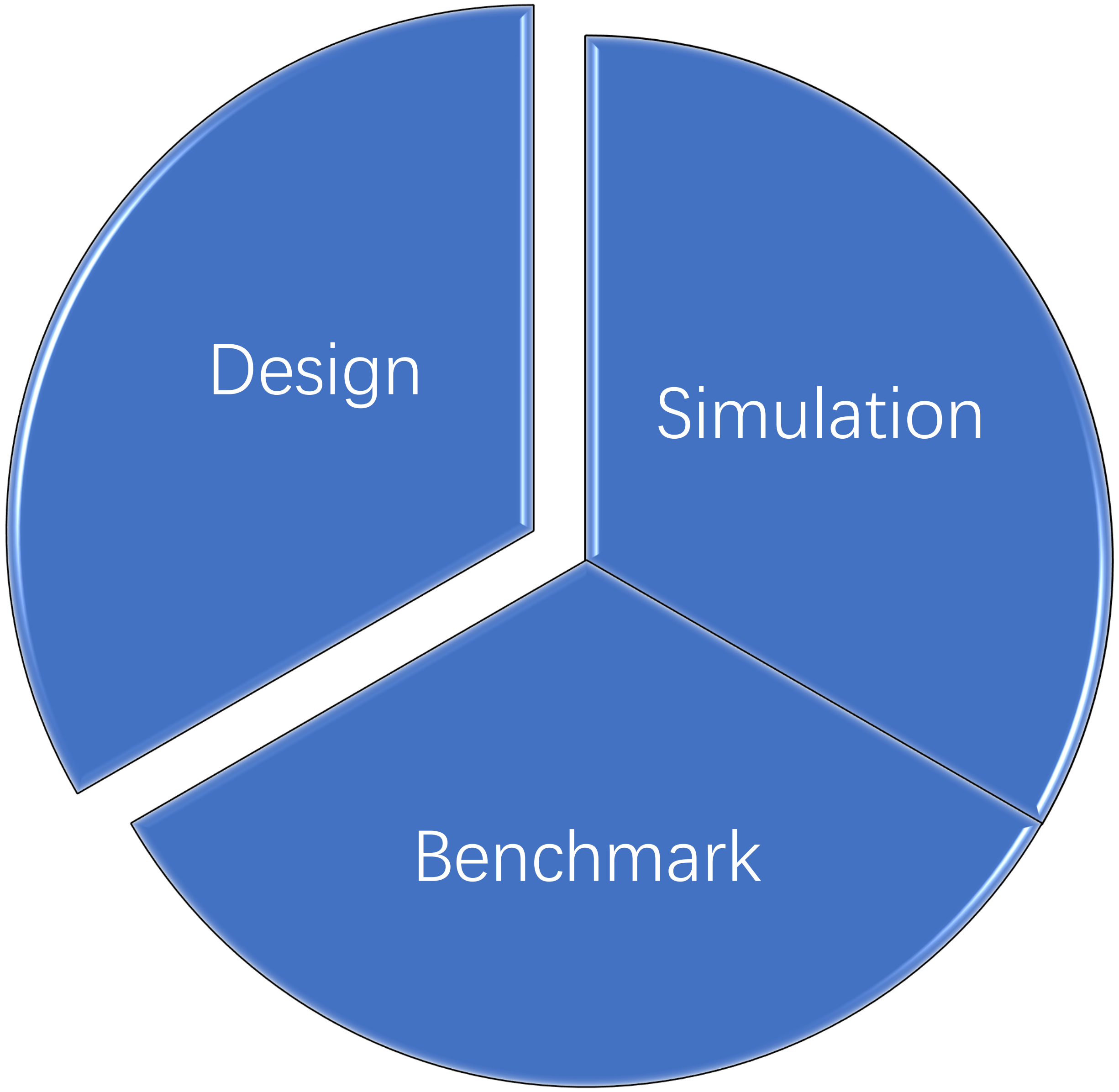
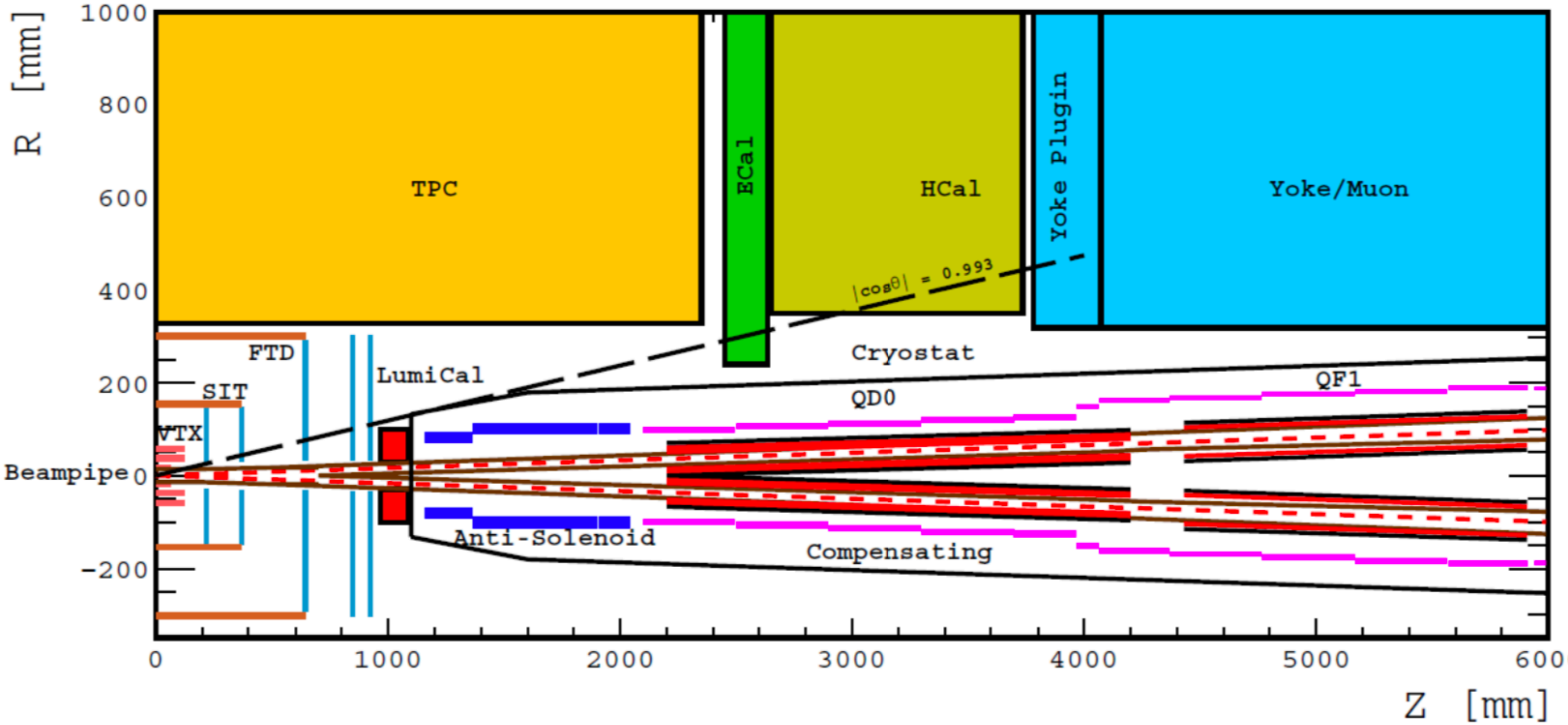


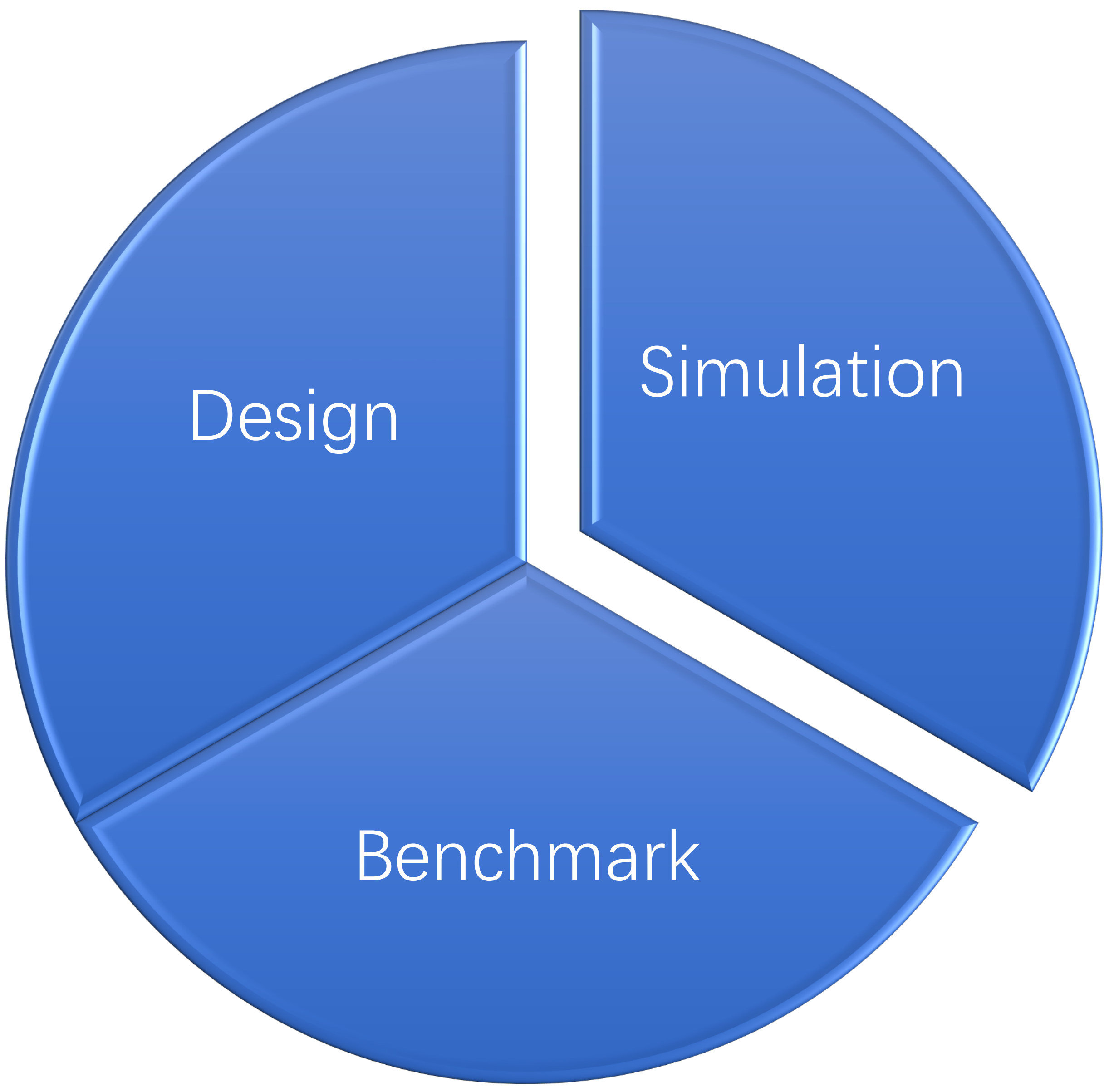

Design
Simulation
Benchmark

Interaction Region Layout



- Based on CDR Design and Parameters for both Detector & Accelerator
- Higgs Mode, One IP, One Beam
- Impact on Vertex Detector

Workflow



Source Analysis

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

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Photons

Off Energy Beam Particles

Workflow

- Simulation workflow 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

Basic Simulation

For Photon BGs and Beam BGs

Using its own Generator.

Using SAD or BDSim as tracking tool.

Using Geant4 to perform full detector simulation

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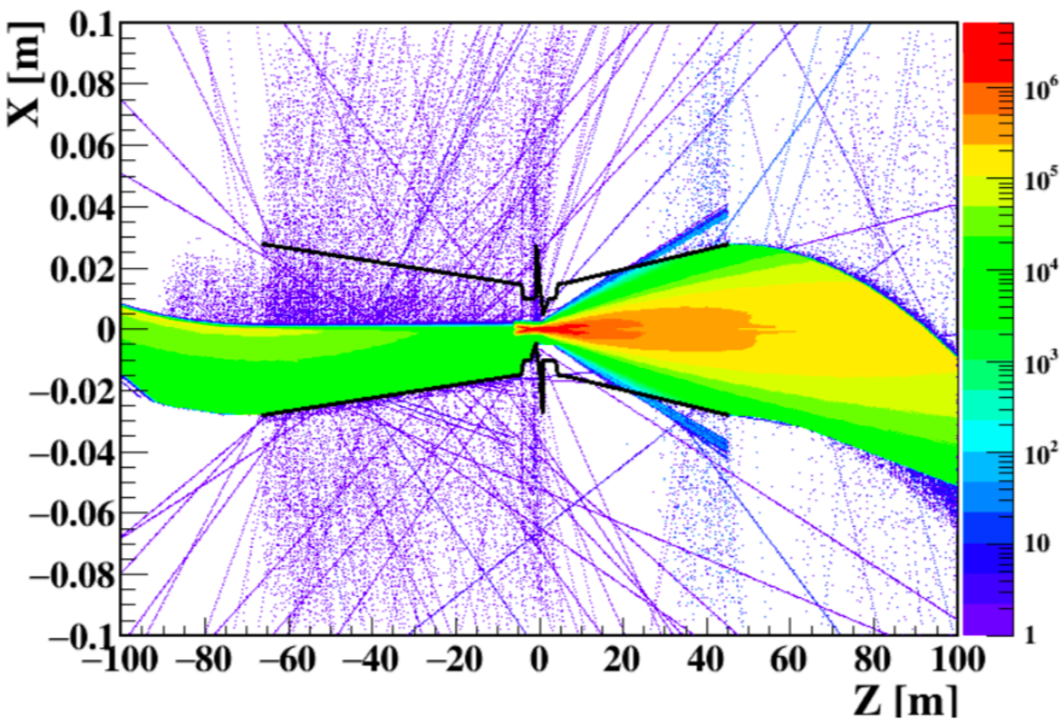
    - Beamstrahlung(Pair Production)
    - Radiative Bhabha Scattering

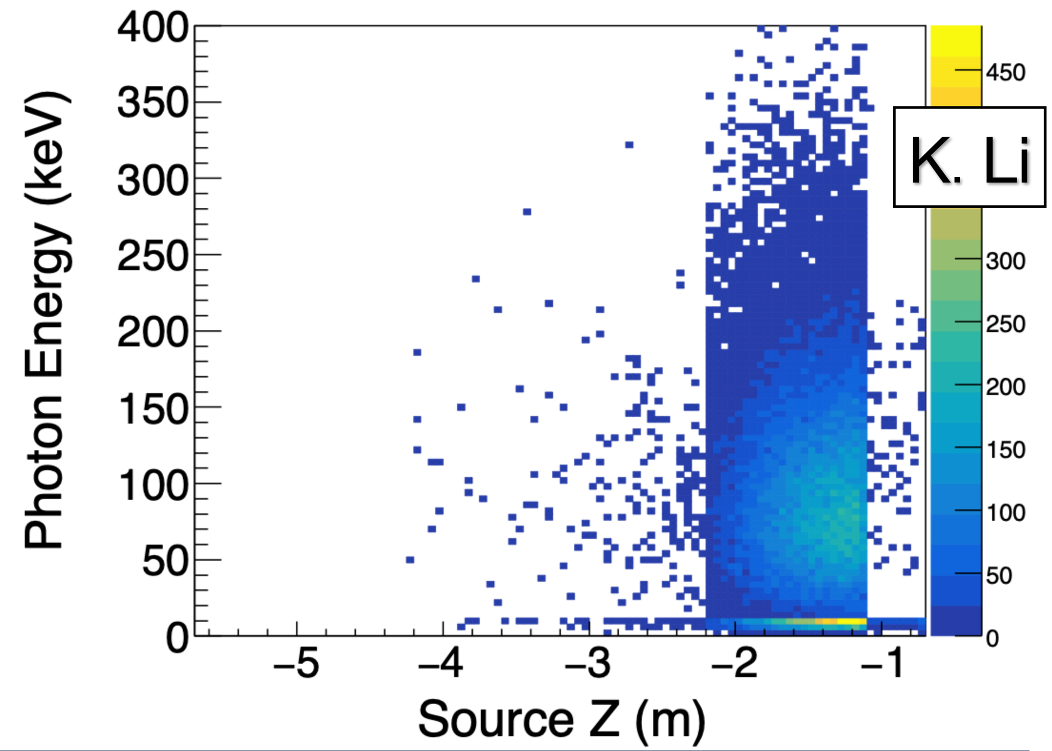
Photons

Off Energy Beam Particles

Synchrotron Radiation

- Beam bent by magnets would emit synchrotron radiation, 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 particles hitting the central beryllium pipe



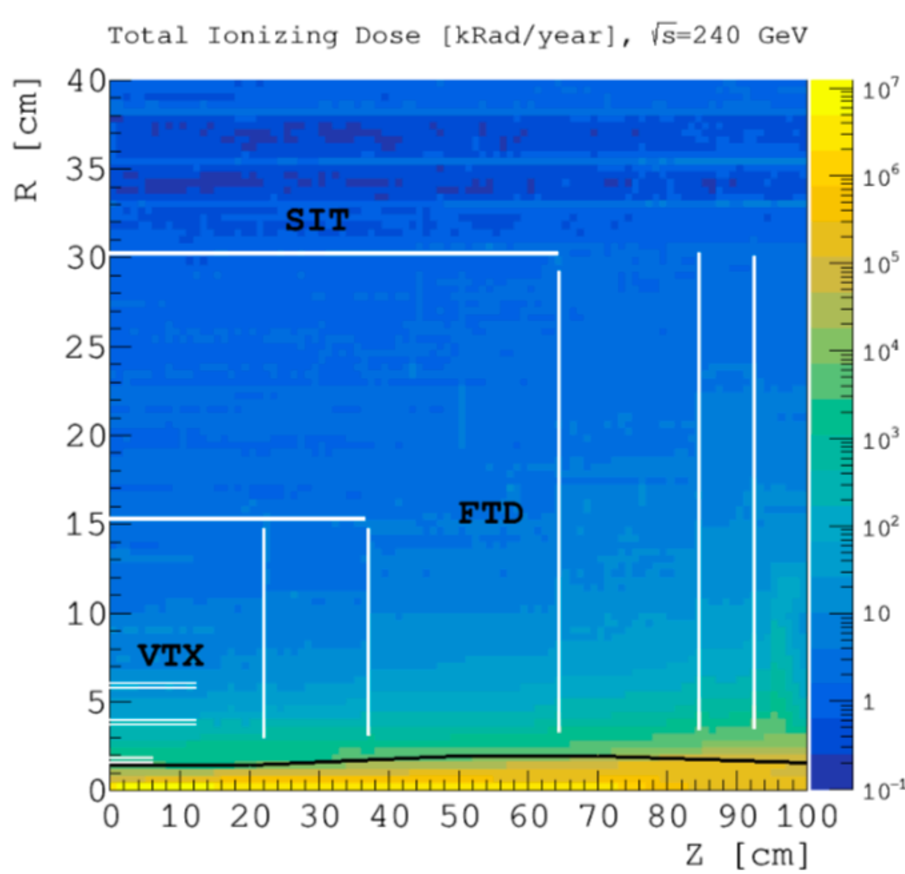


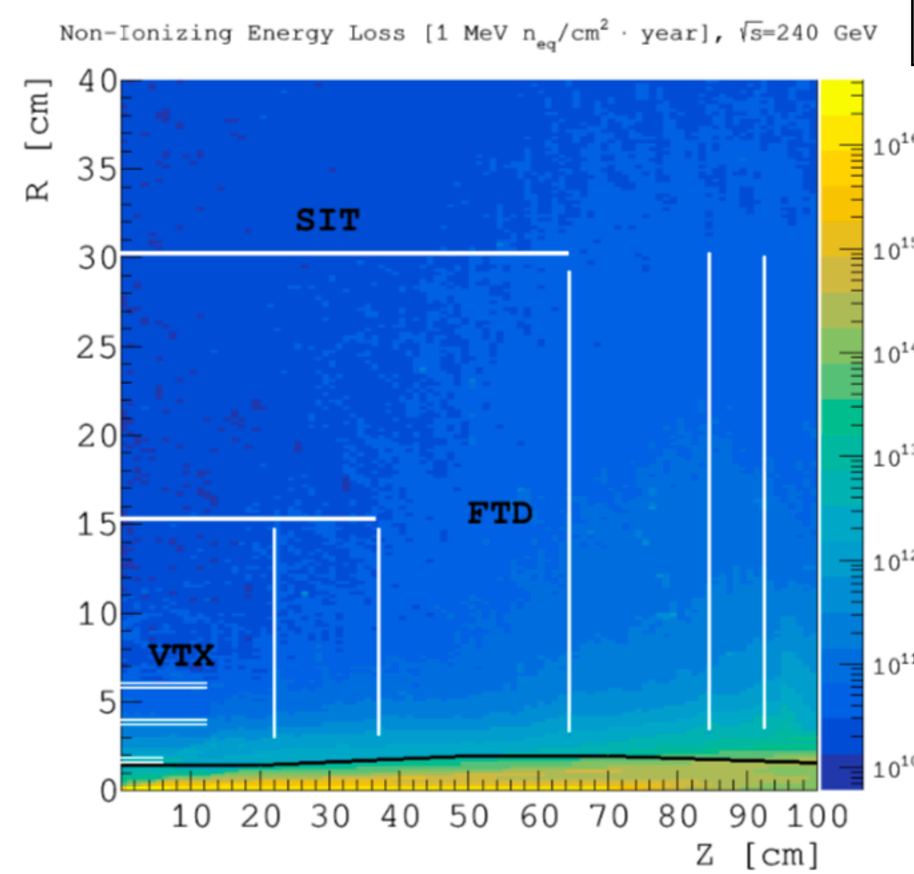
Background Type	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)
Synchrotron Radiation	~18.2	~584.0

Pair Production

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

W. Xu





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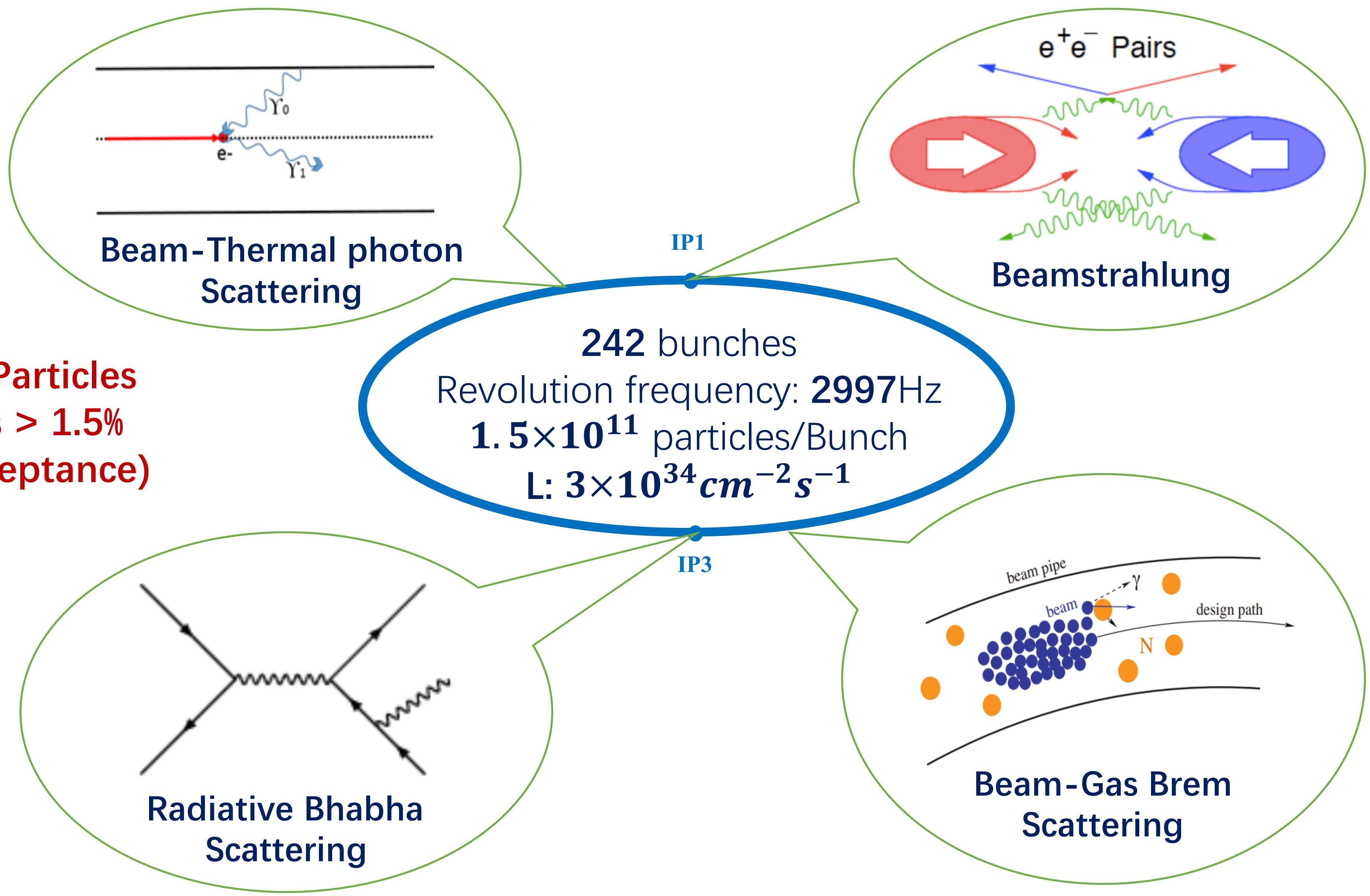
Photons

Off Energy Beam Particles

CEPC Beam Lifetime

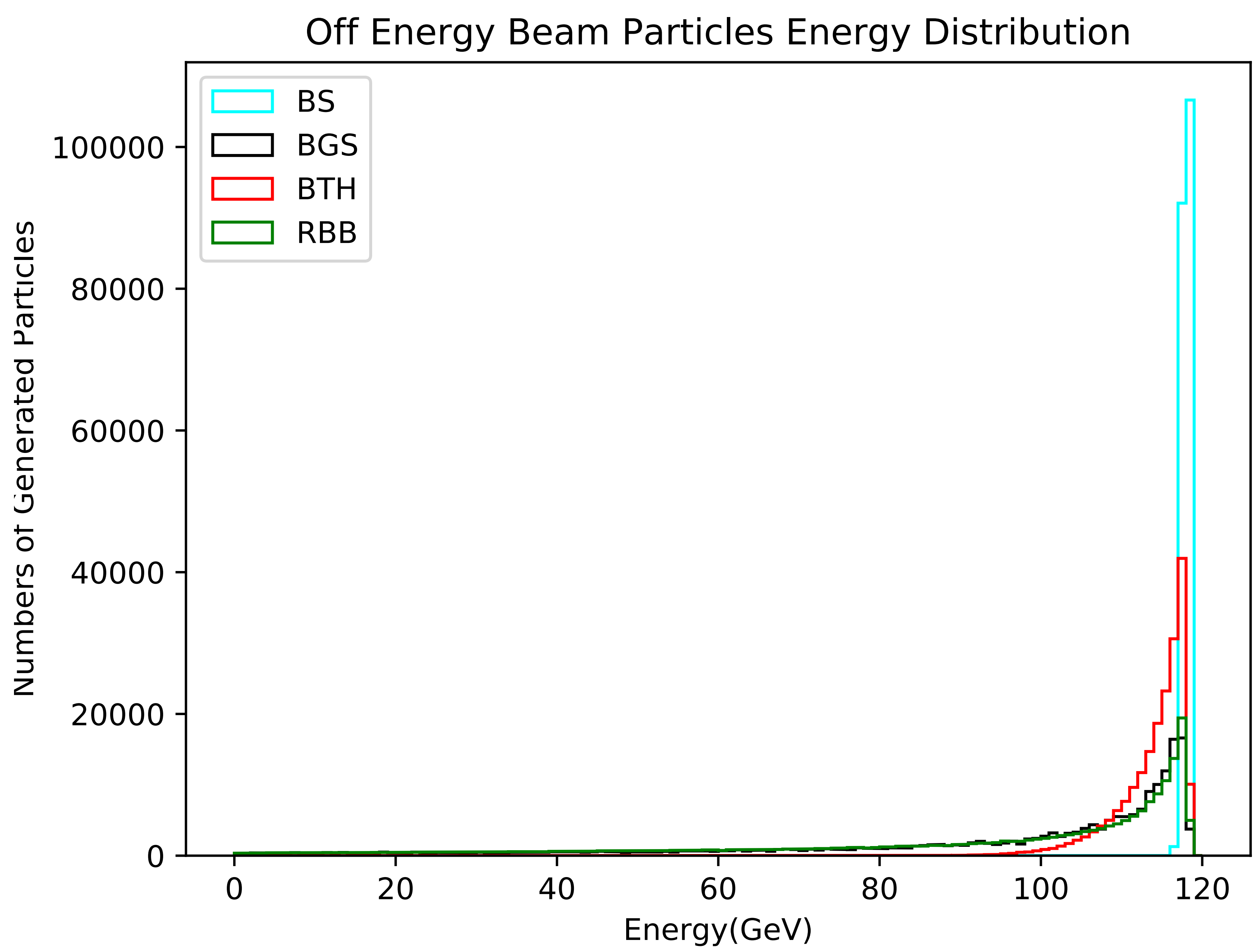
	Beam Lifetime	Others
Touschek effect	>1000 h	
Beam Gas Coulomb	>400 h	CO, 10^{-7} Pa
Beam Gas Bremsstrahlung	63.8 h	
Beam Thermal Photon Scattering	50.7 h	
Radiative bhabha Scattering	74 min	
Beamstrahlung	80 min	

Off Energy Beam



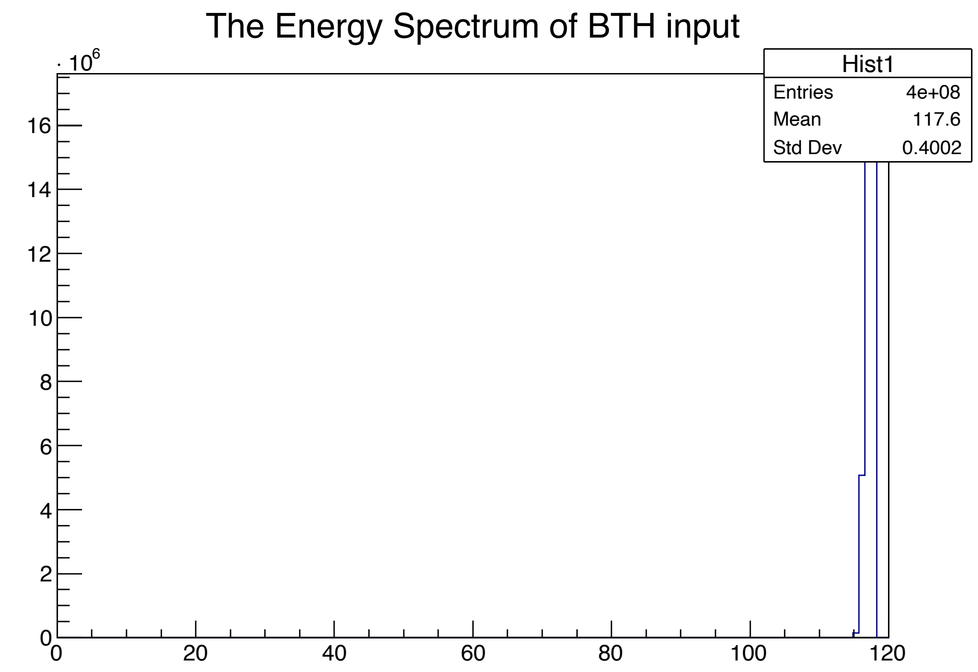
Beam Lost Particles
Energy Loss > 1.5%
(energy acceptance)

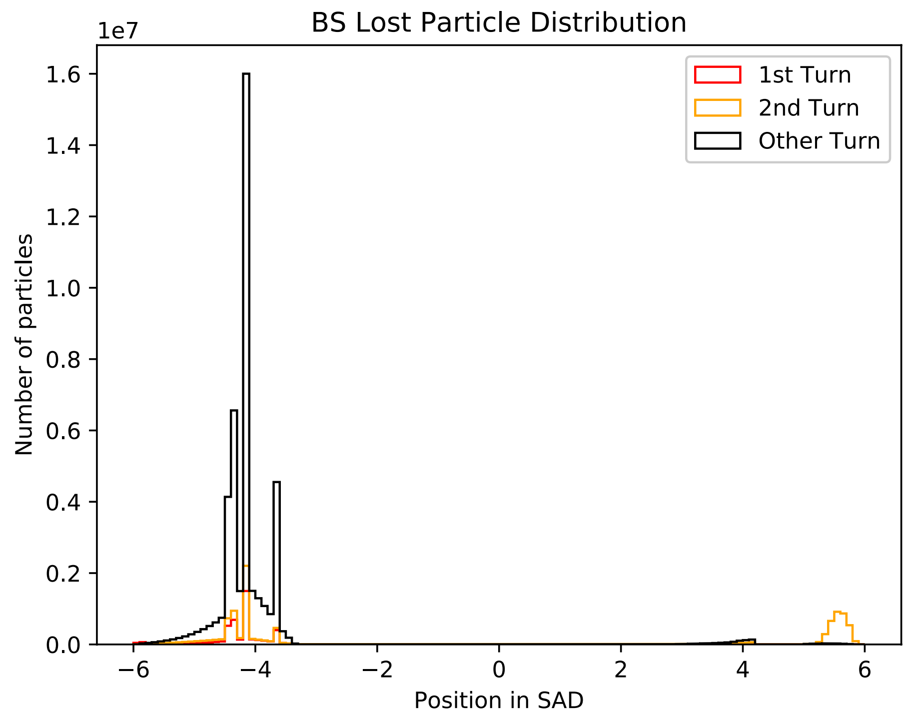
Energy Spectrum



Beamstrahlung

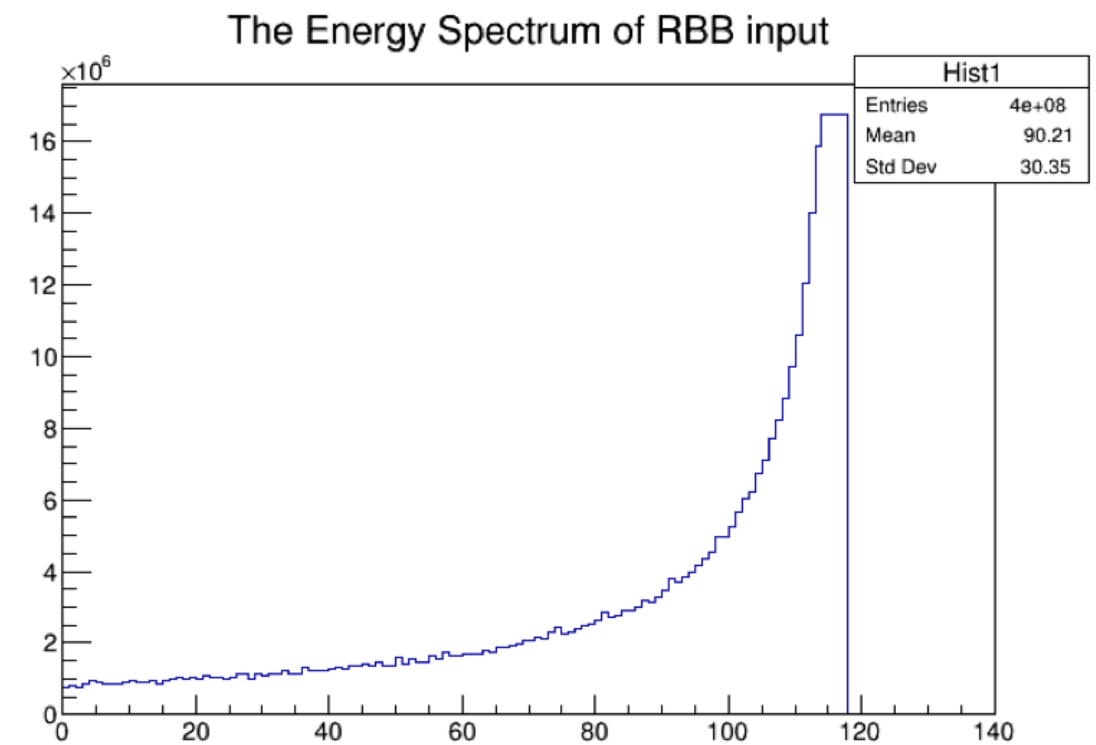
- Beamstrahlung is the radiation background from one beam of charged particles in storage rings or linear colliders caused by its interaction with the electromagnetic field of the other beam
- Generated by formula(PyBS)
  - Code Written by Dr. Yue
- Checked with Guinea-Pig++

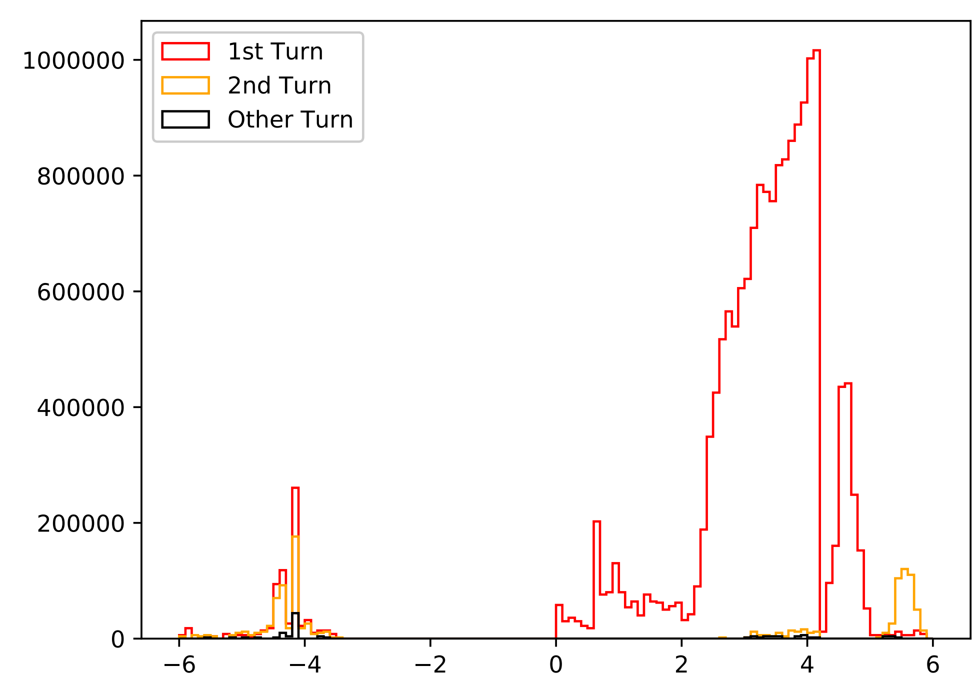




Radiative Bhabha

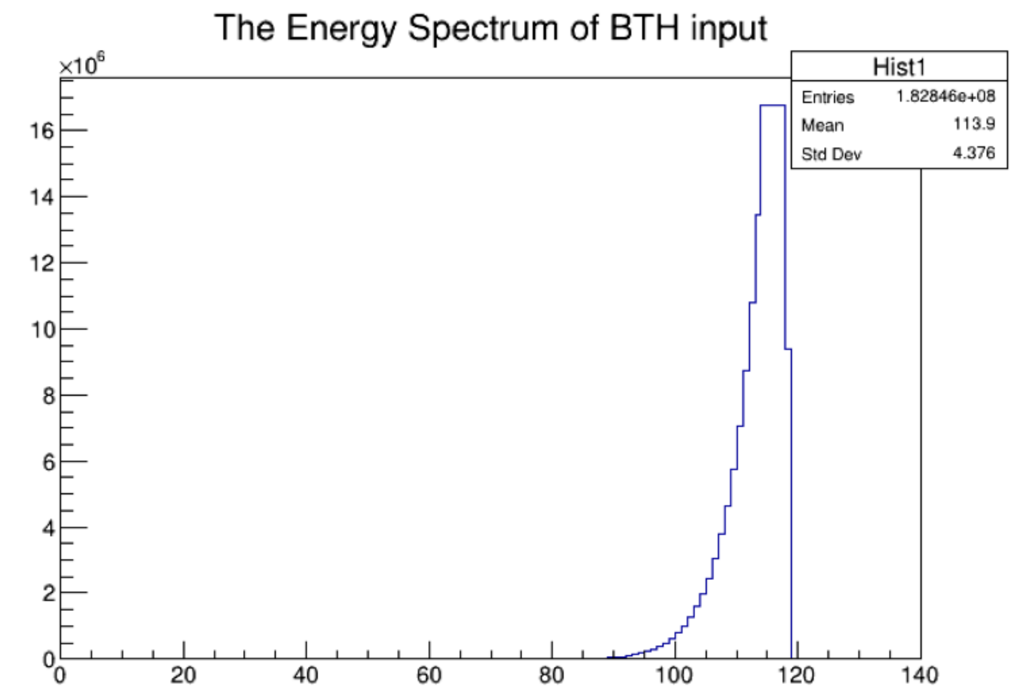
- Radiative bhabha scattering represents the progress that one electron/position interact with the other and emit photons. The electron/position could loss energy, and might become background.
- Generated by bbbrem
- Could also generated by formula(Py_RBB)
  - Code Written by Dr. Yue

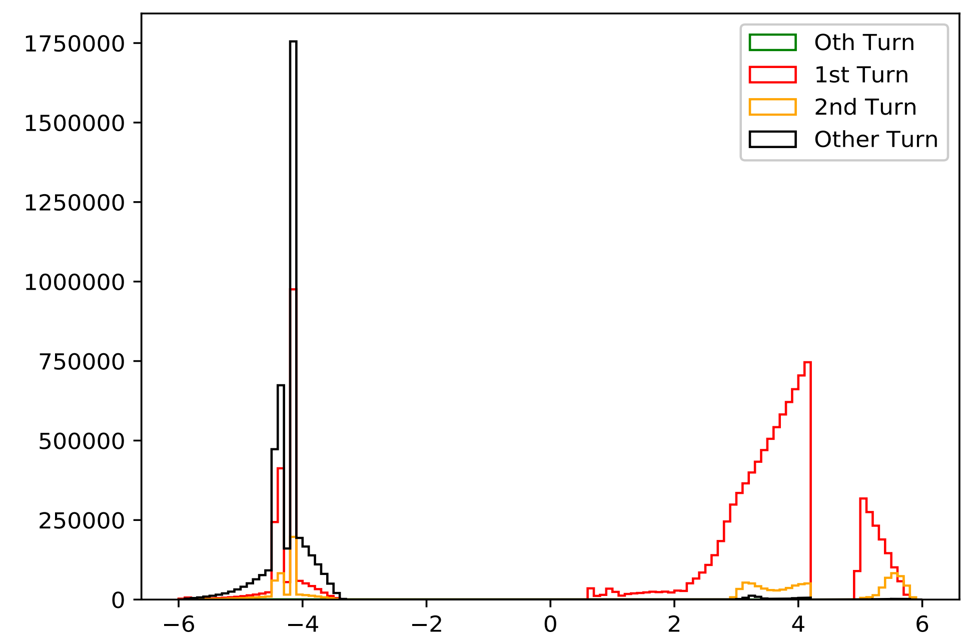




Beam Thermal Photon

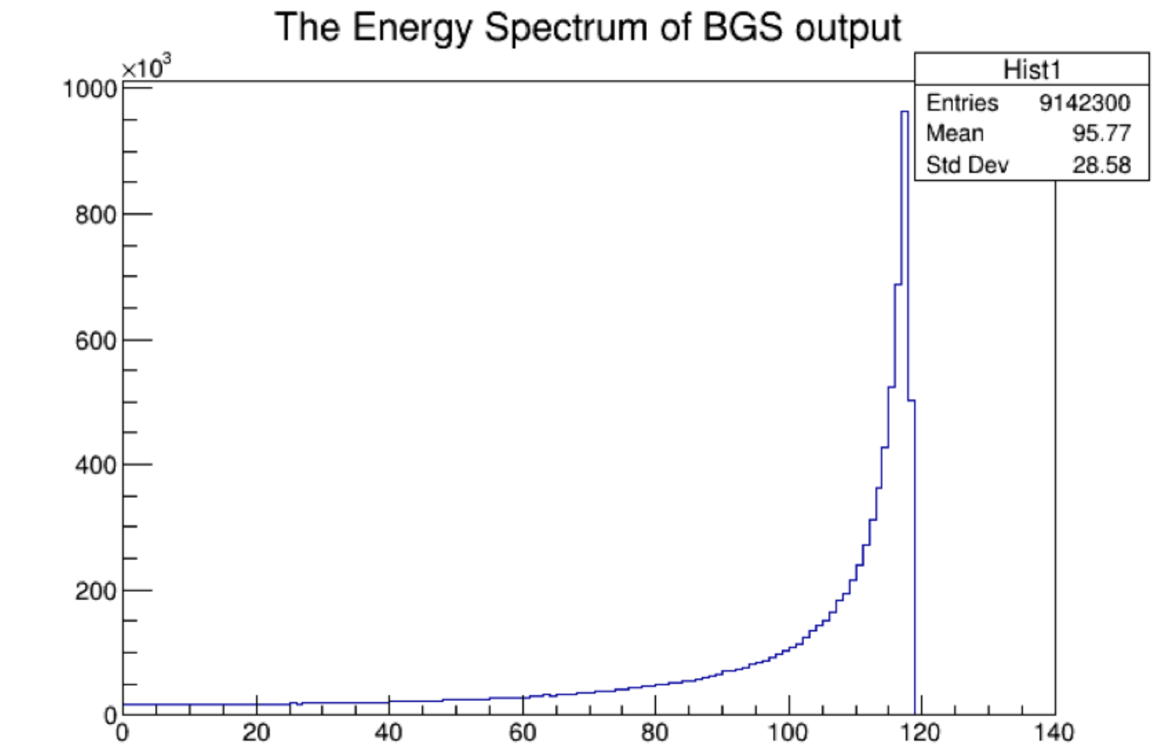
- Beam Particle interact with the photon emitted by beam pipe
  - Important on high energy machine
- The same as Beam-Gas:
- Generated by PyBTH:
  - Written by Dr. Yue
  - The scattering was generated with 200 meters to the IP
  - Tracking whole ring for many turns

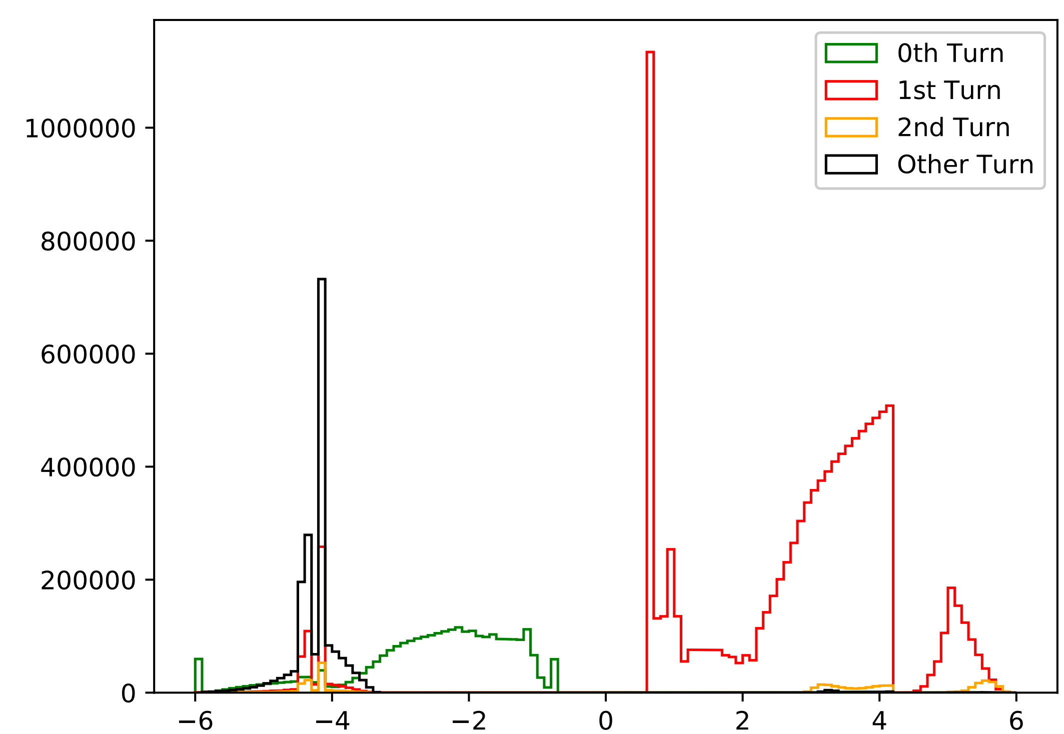




Beam Gas

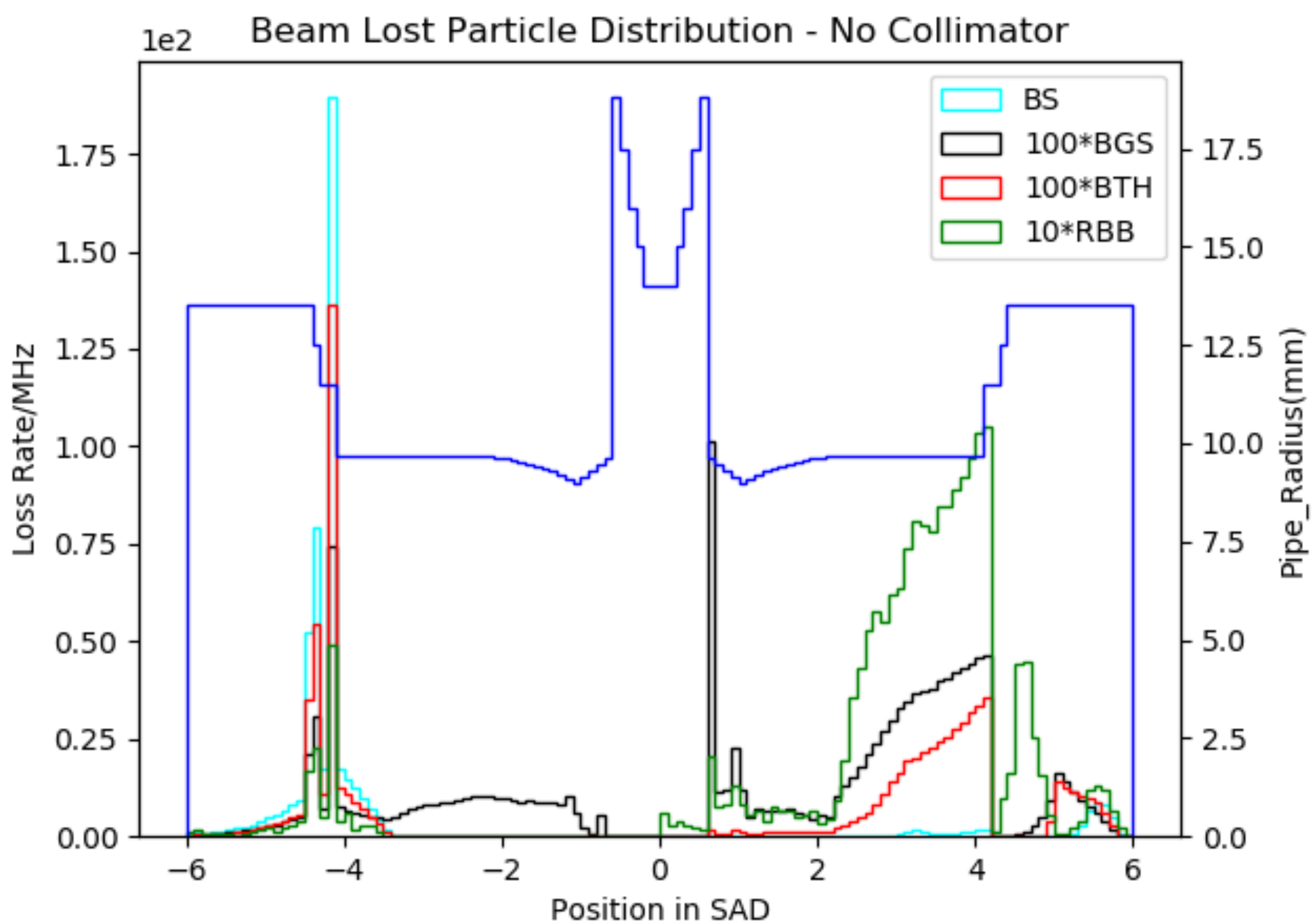
- Beam Particle interact with residual gas
- Beam-Gas Inelastic Scattering:
  - With nuclei
  - With electron
  - σ doesn't relevant with energy, has strong impact on both high and low energy machine
- Generated by PyBGS2
  - Written by Dr. Yue
  - Residual Gas CO, with $10^{-7}Pa$
  - The scattering was generated with 200 meters to the IP
  - Tracking whole ring for many turns





Lost Distribution without Collimators

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



Ways to Mitigate

1. Using Shielding/Mask/Collimator
2. Others?

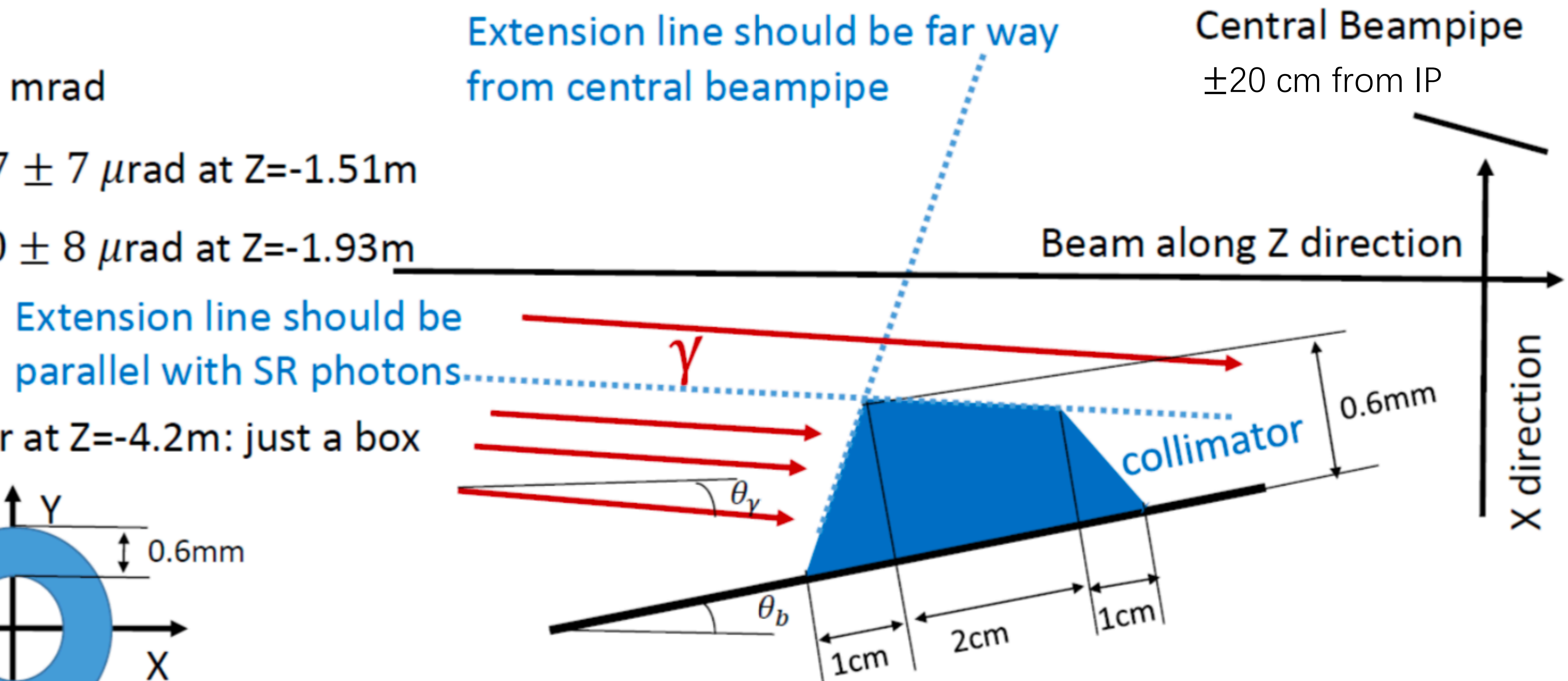
SR Mask

K. Li

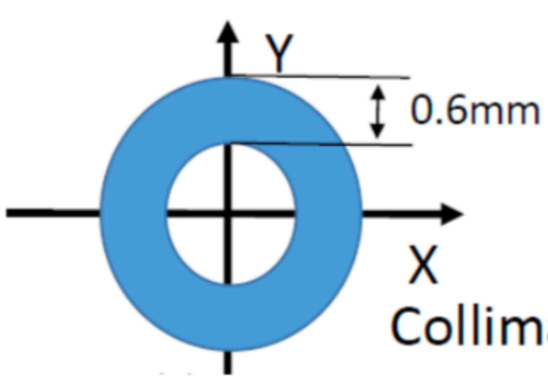
θ_b= 1.17 mrad

$\theta_\gamma = -127 \pm 7\ \mu$rad at Z=-1.51m

$\theta_\gamma = -130 \pm 8\ \mu$rad at Z=-1.93m

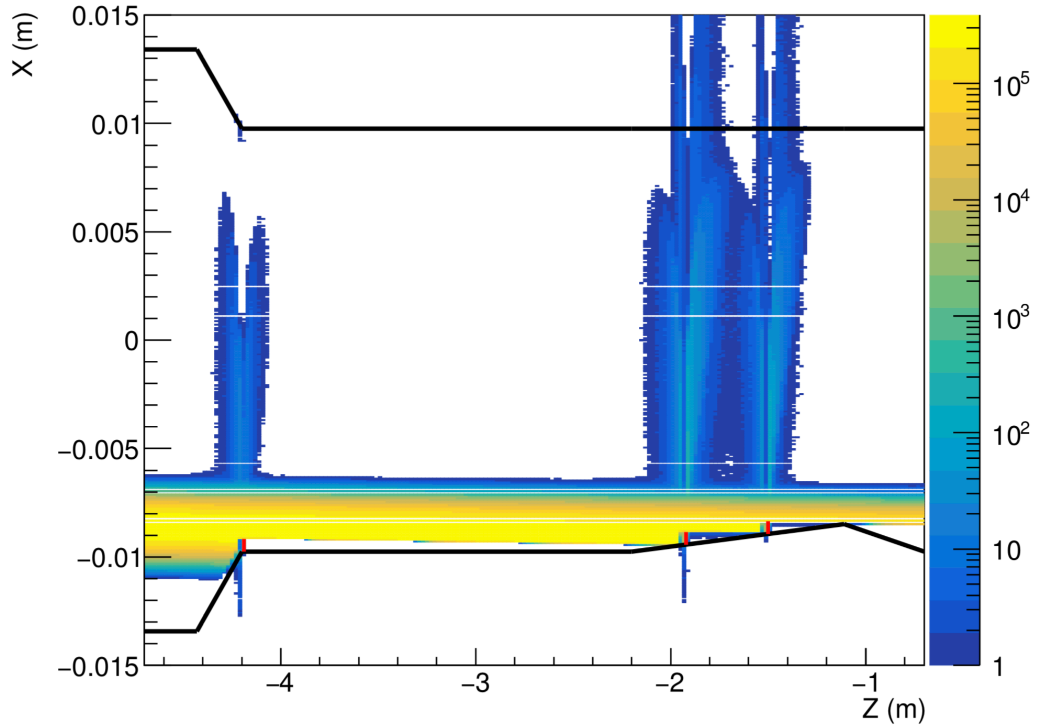


Collimator at Z=-4.2m: just a box

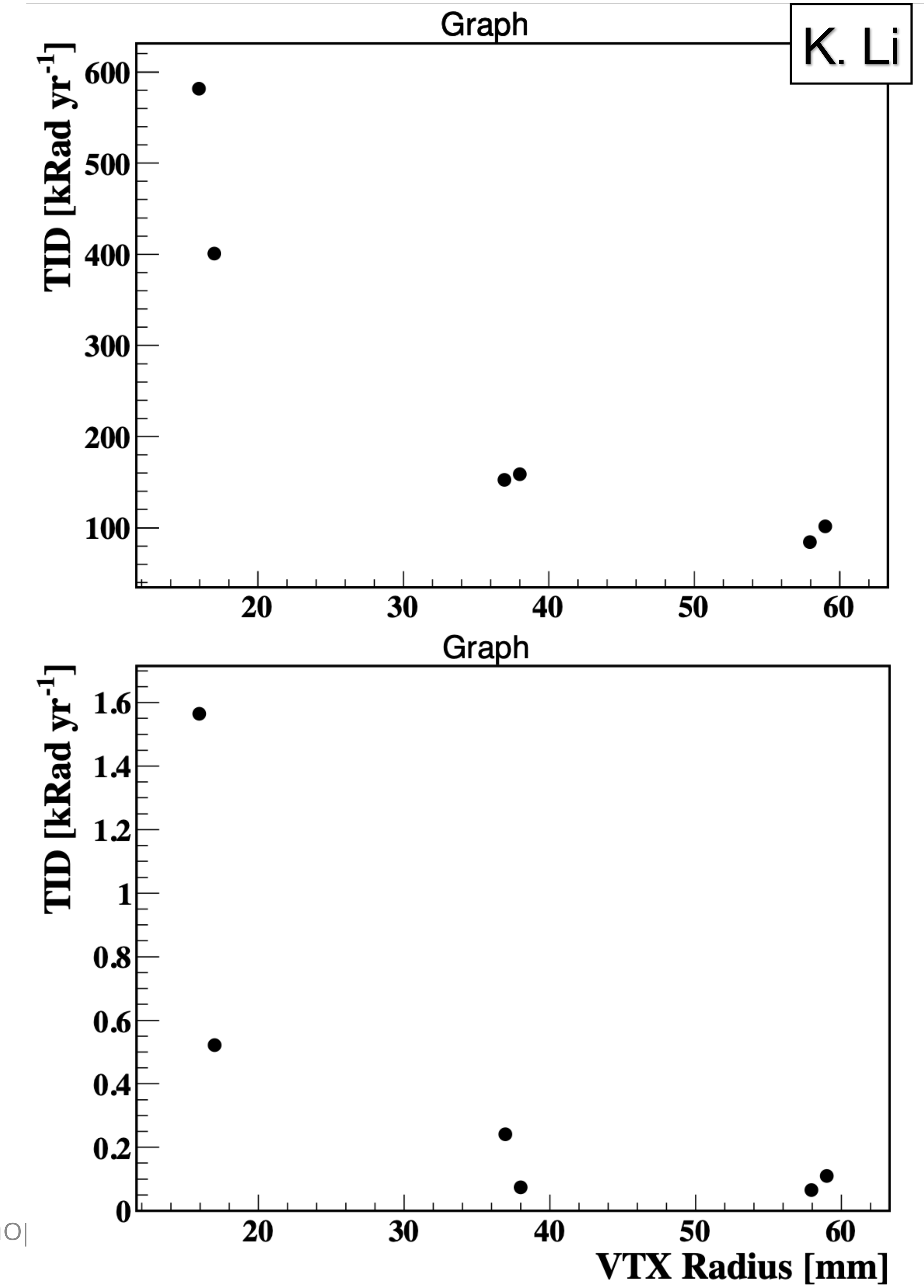


Collimator at X-Y plane: a ring

Effectiveness



- With masks located at -4.2, -1.93 and -1.51m along the beam pipe to shield the central beam pipe.
- Detector hit numbers could be decreased from 7.73×10^4 down to 111 per bunch.



Collimator

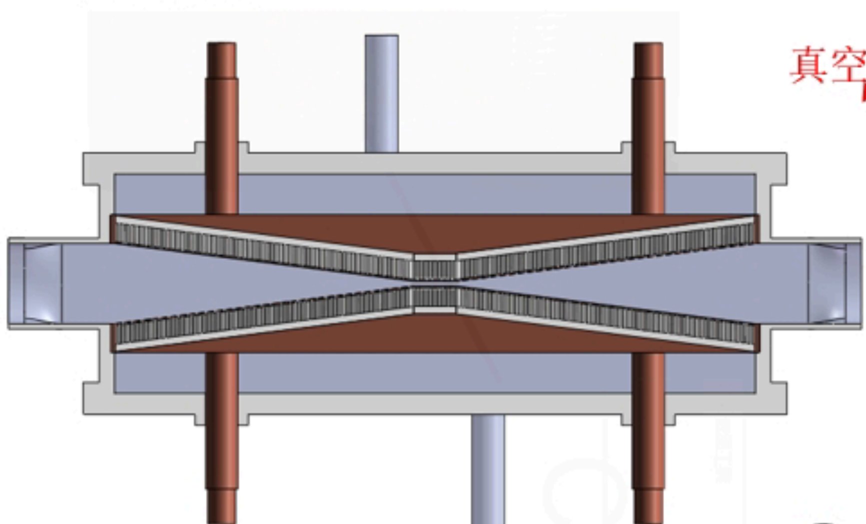
- Collimators are need.
- Now we put 2 sets of horizontal collimators, but sure to need more in future.(Trying 5th Horizontal one upstream of IR)
  - SKEKB has about 30 sets
- We only take primary into consideration.

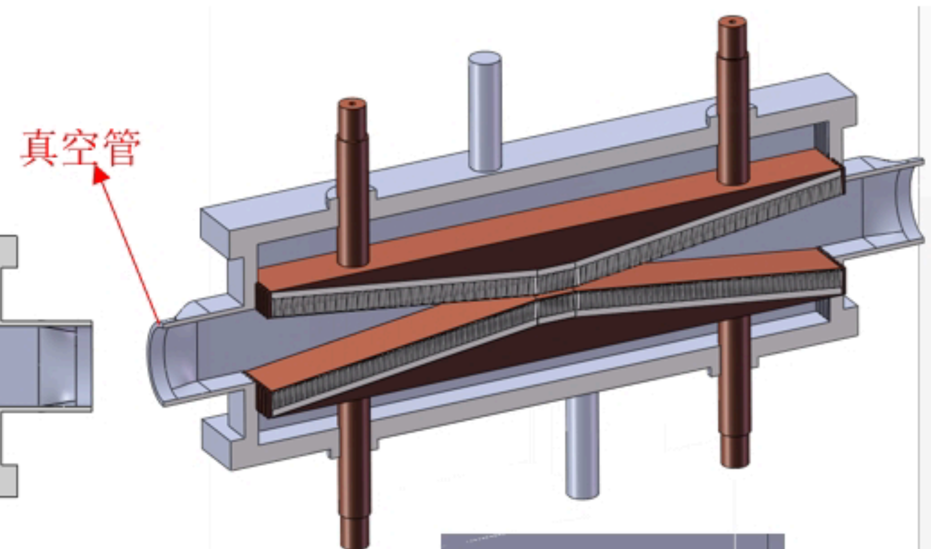
S. Bai

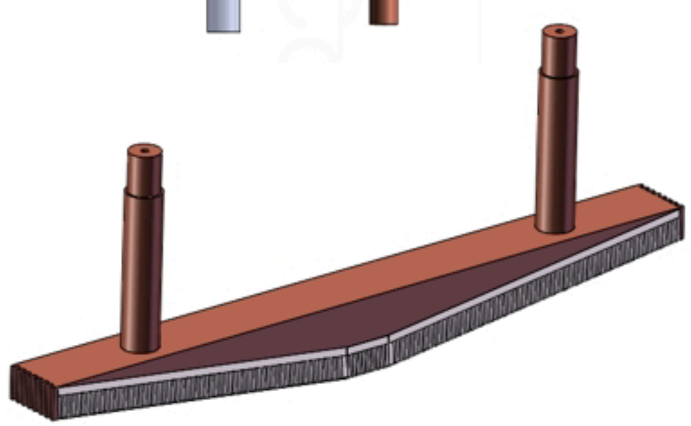
Name	Location	Distance to IP
APTX1	D1I.1897	2139.06
APTX2	D1I.1894	2207.63
APTX3	D1O.10	1832.52
APTX4	D1O.14	1901.09

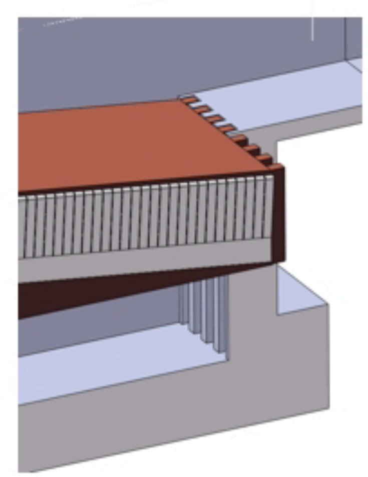
Collimator

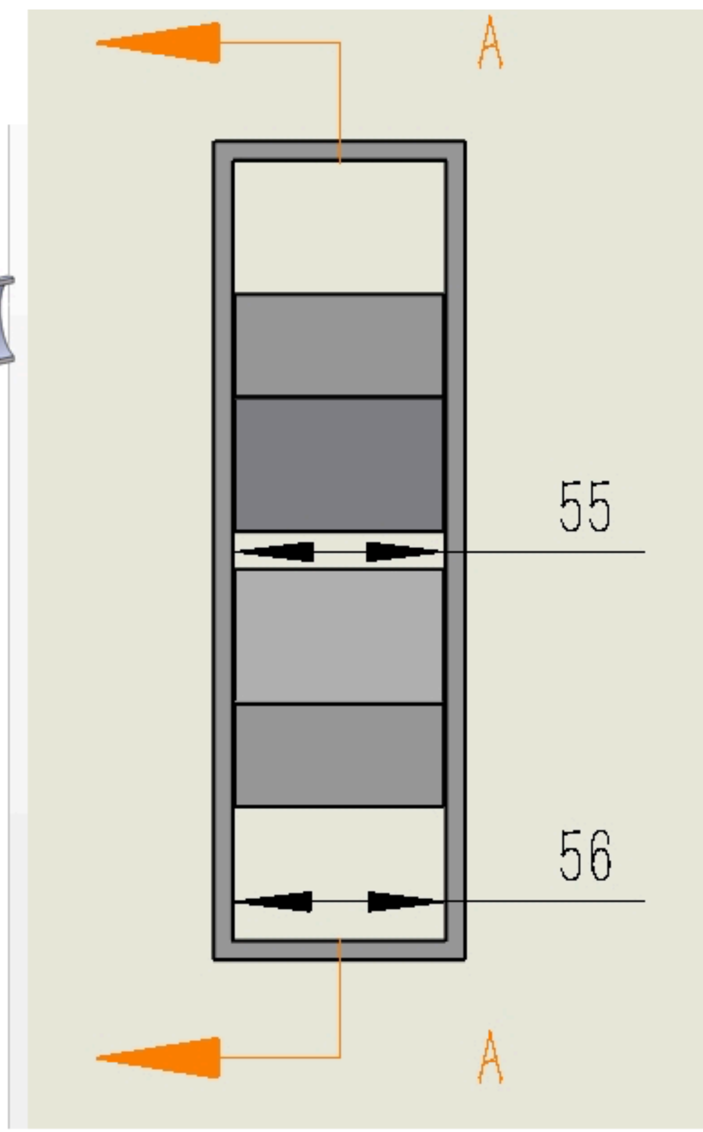
- 矩形腔方案



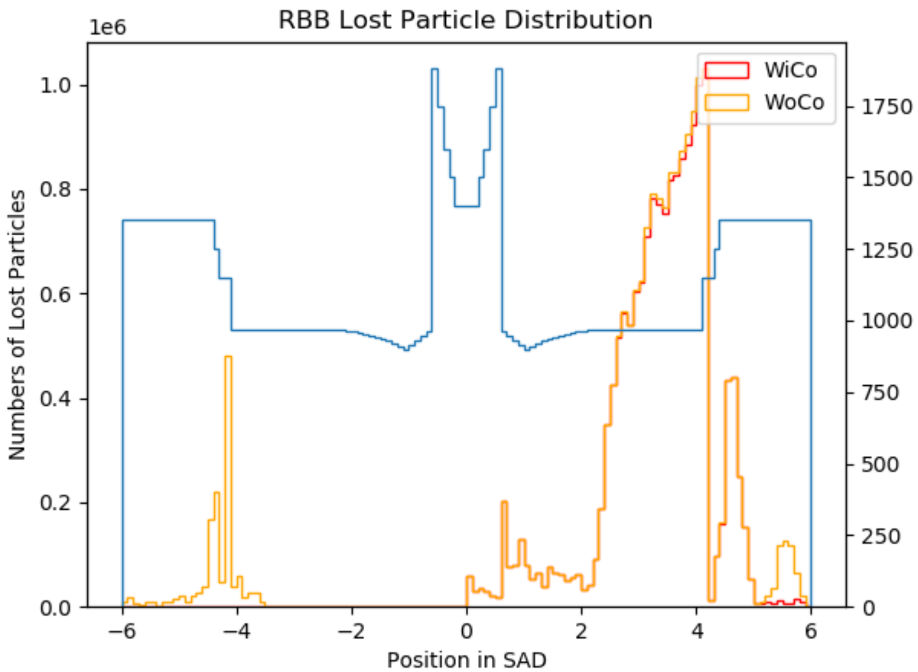


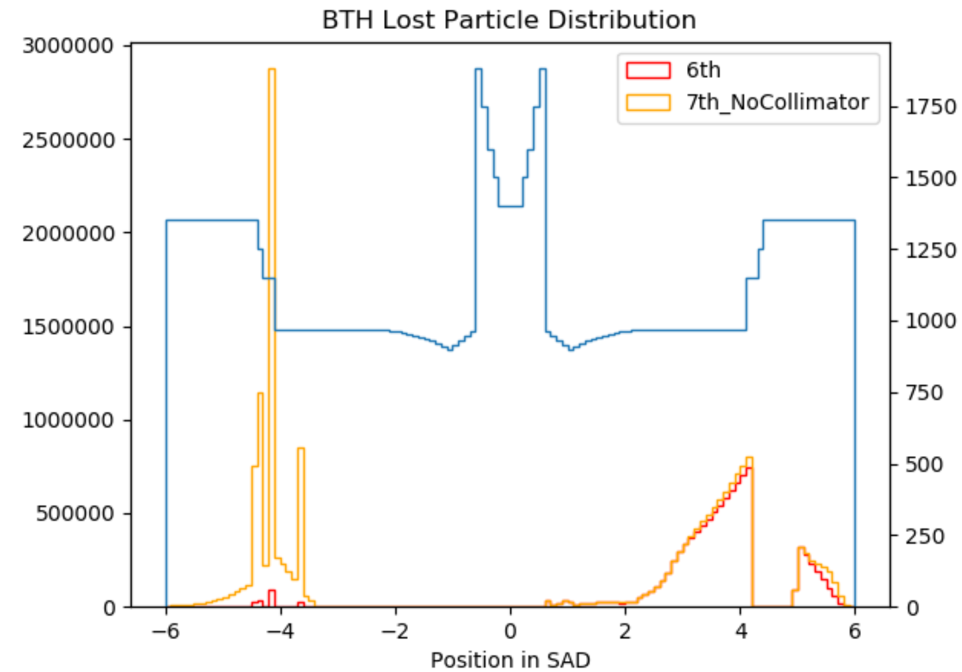


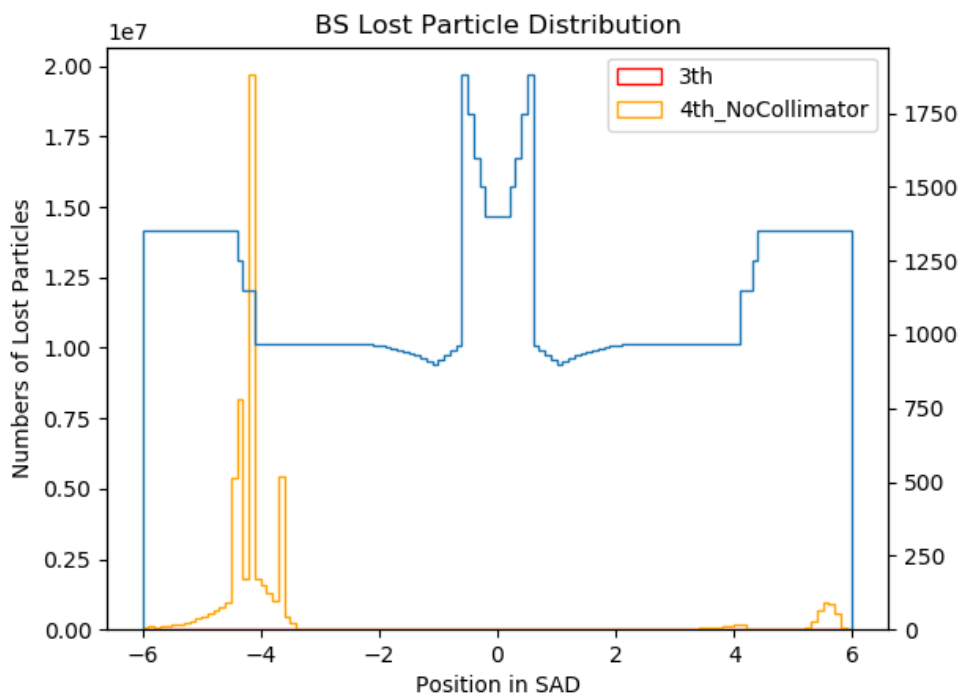


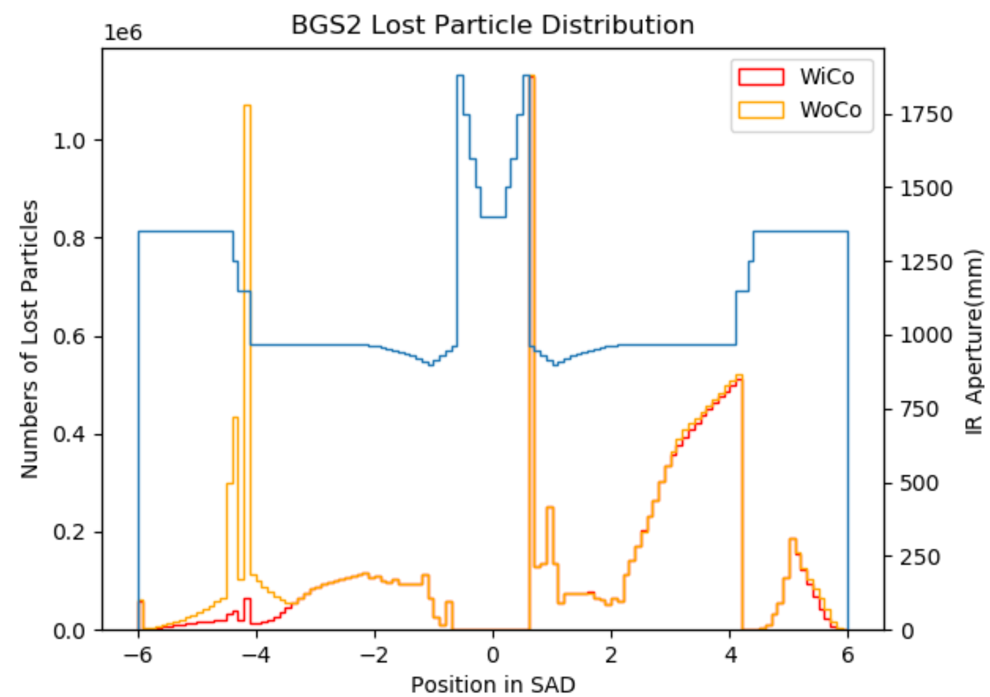


Collimator Effects

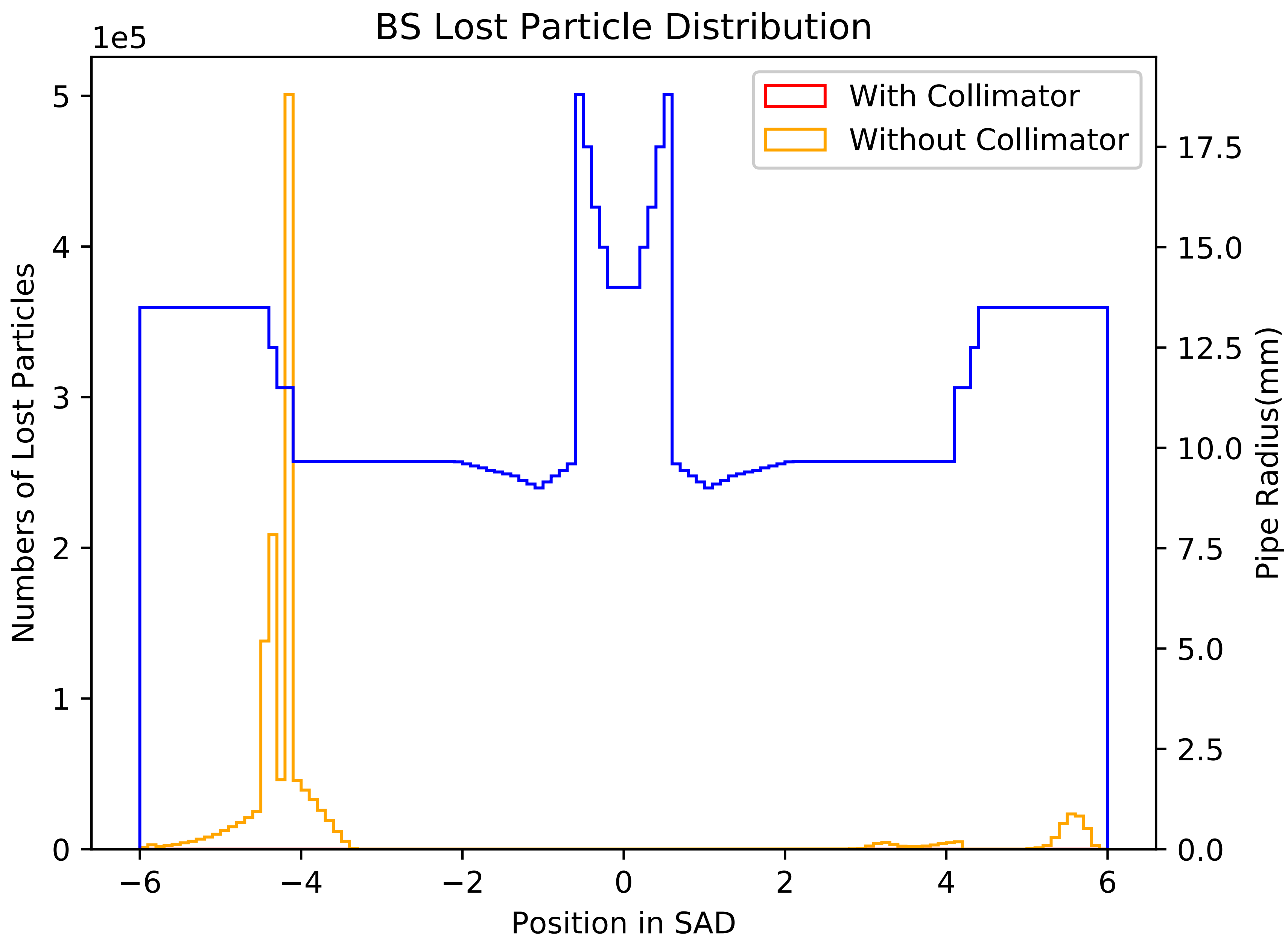




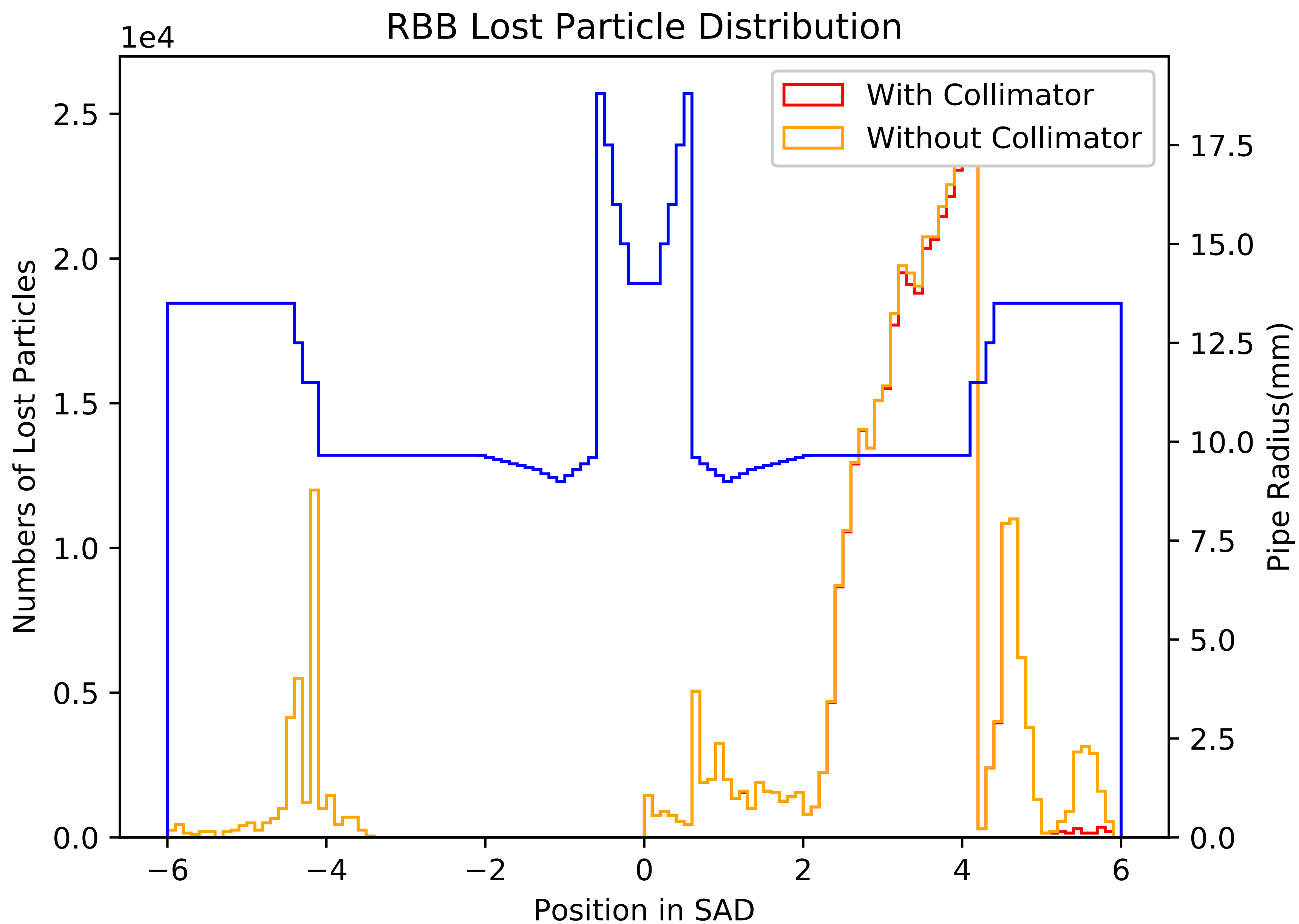




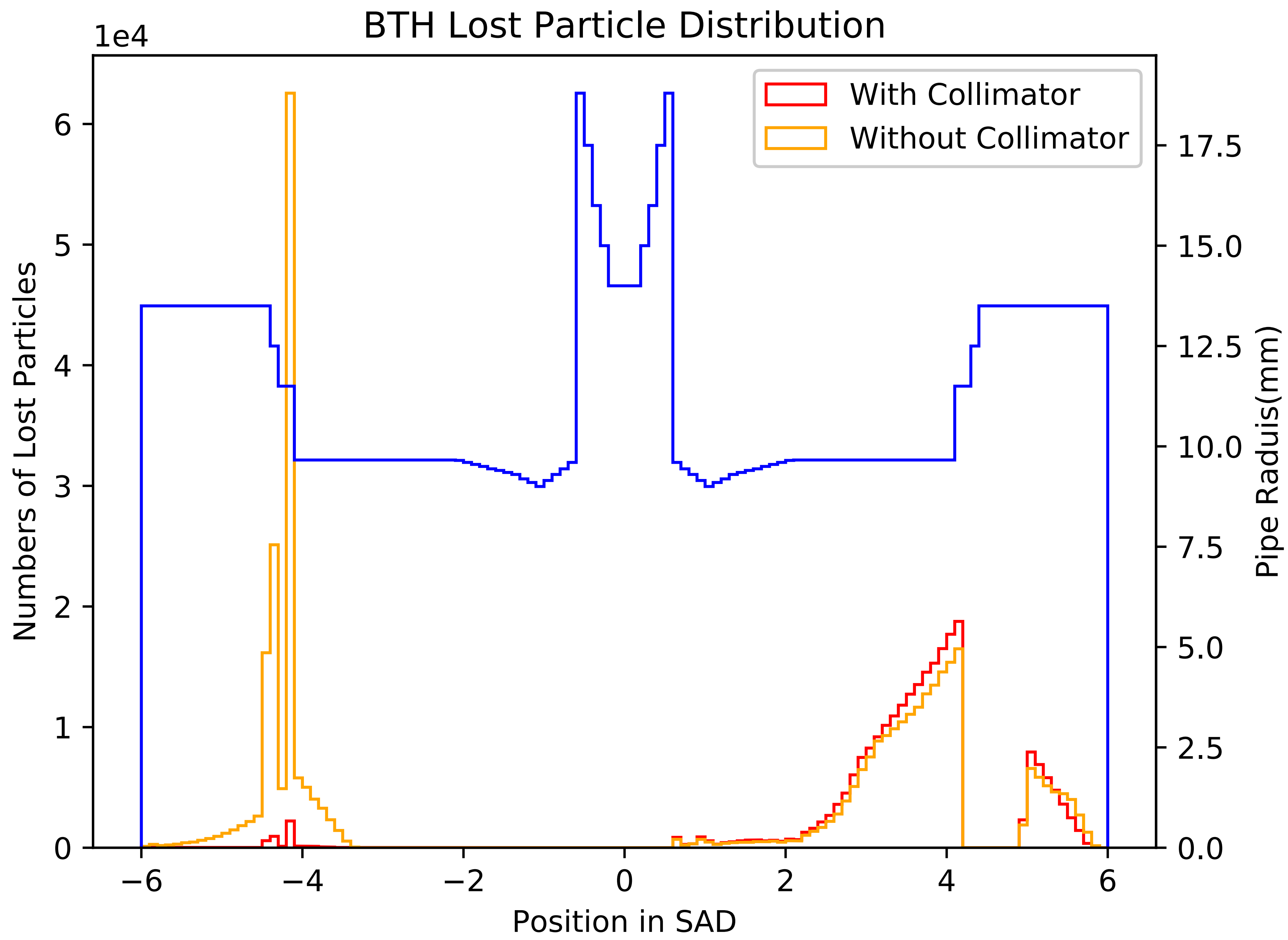
Collimator Effects - BS



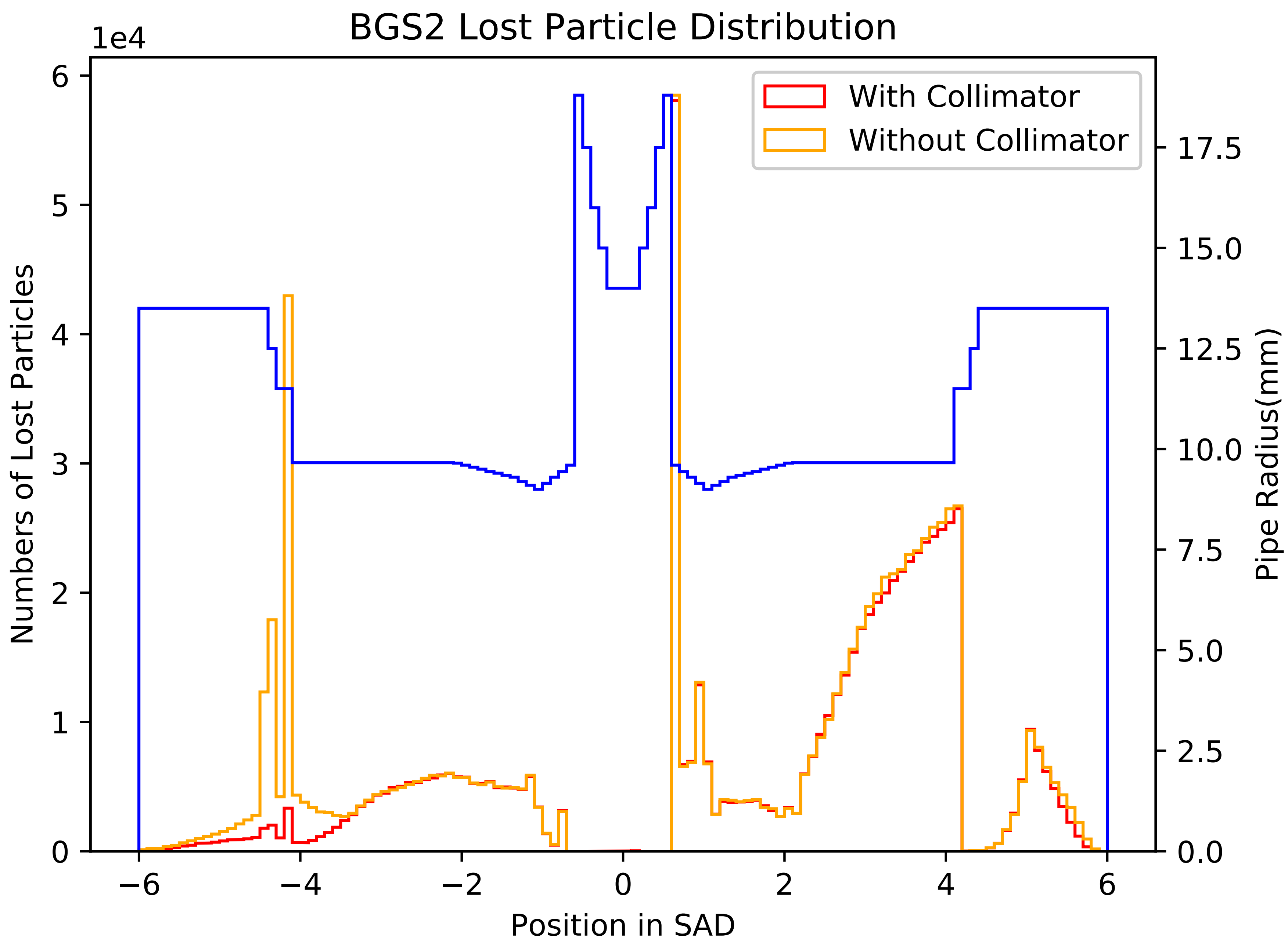
Collimator Effects - RBB



Collimator Effects - BTH

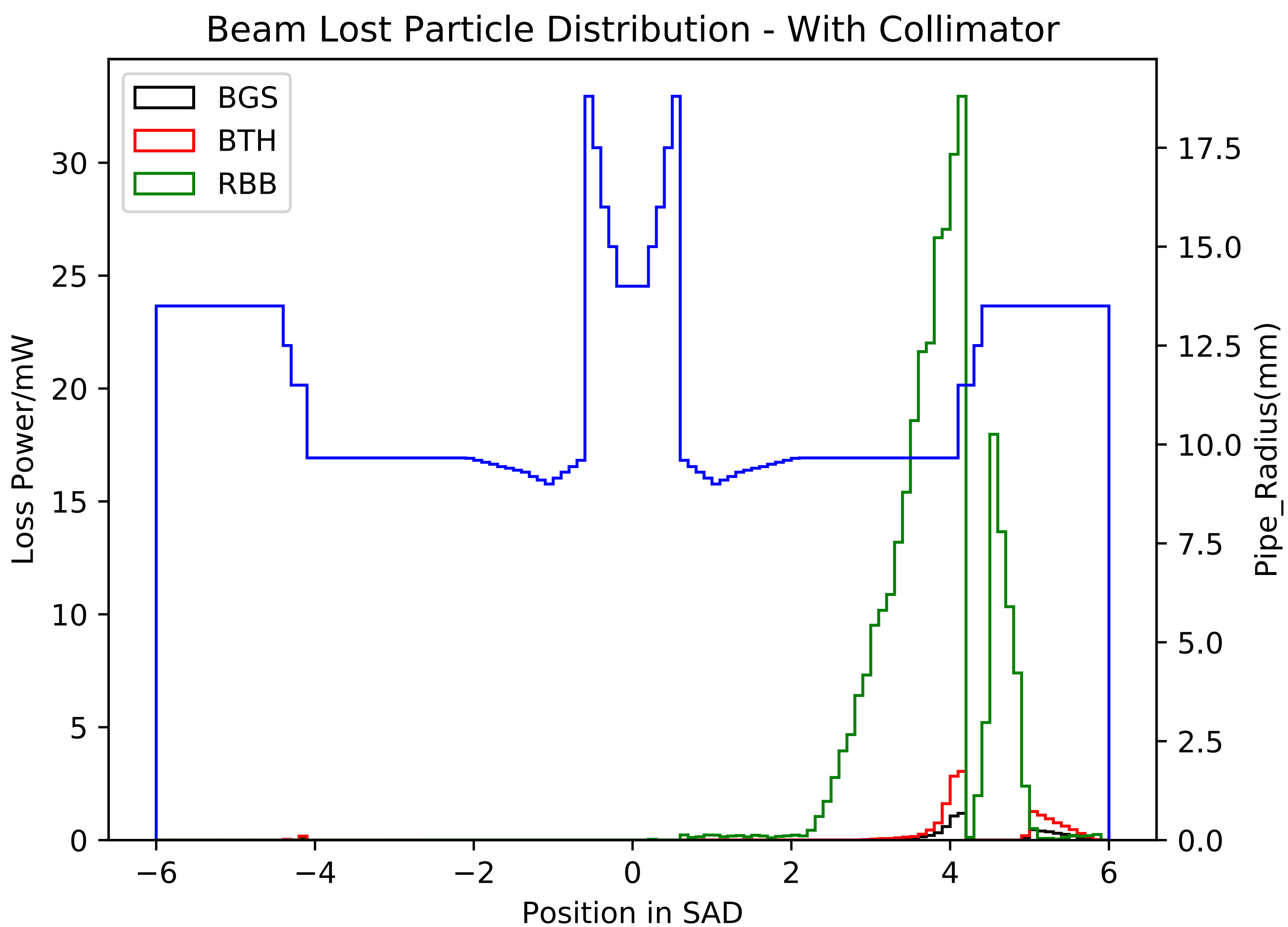


Collimator Effects – BGS2



Lost Distribution with Collimators

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



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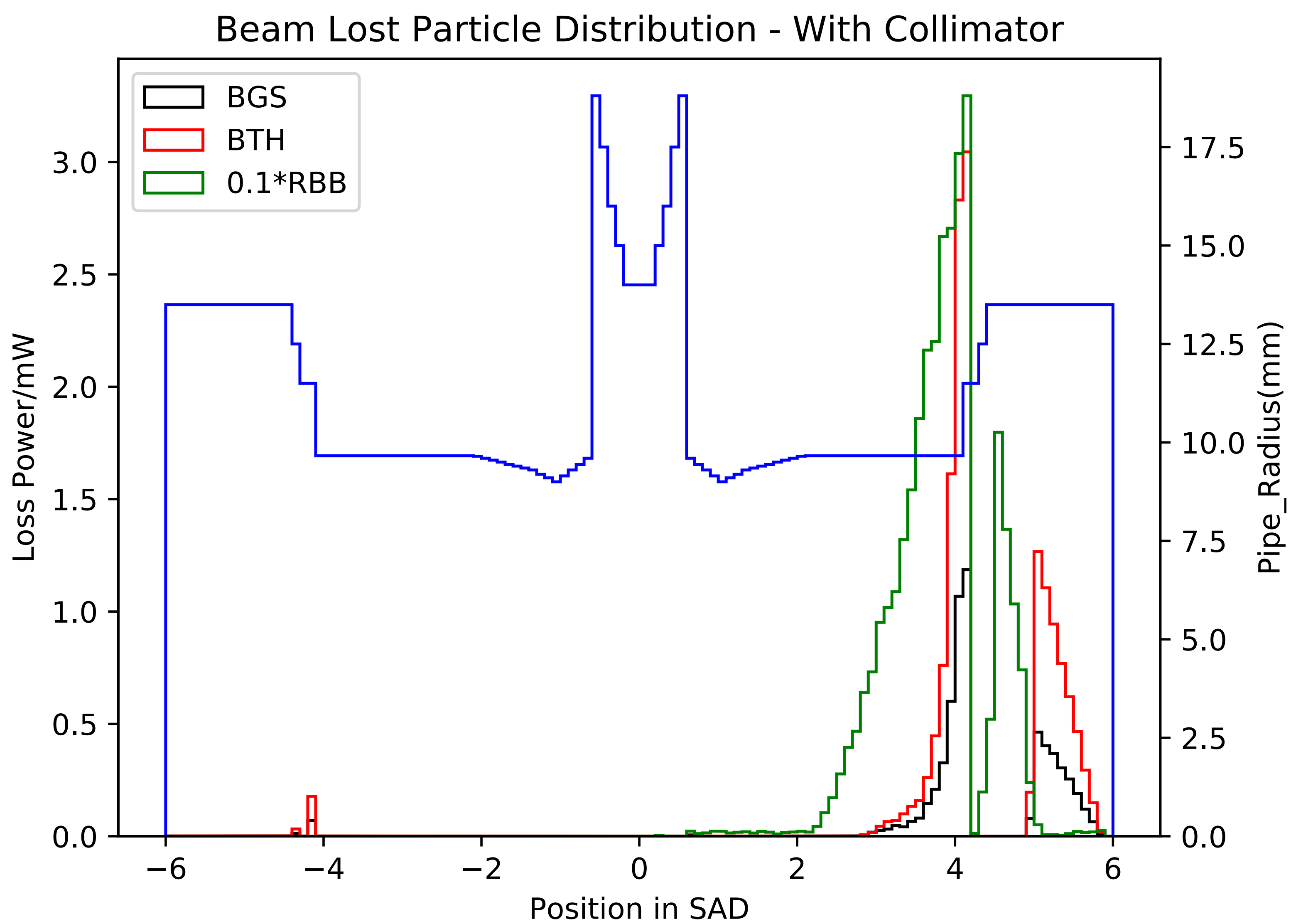


Combine Results

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	2.26	591.14	1.11×10^{12}
Synchrotron Radiation	0.026	15.65	
Radiative Bhabha	0.34	592.66	1.44×10^{12}
Beam Gas	368.372	399013.39	965.0×10^{12}
Beam Thermal Photon	2.31	2325.49	5.48×10^{12}
Total	373.308	402537.83	9.7303×10^{14}

Thoughts to Mitigate BGS Bremsstrahlung

1. Fixing Lost Ratio within IR
2. Improve Vacuum
3. Adding More Collimator

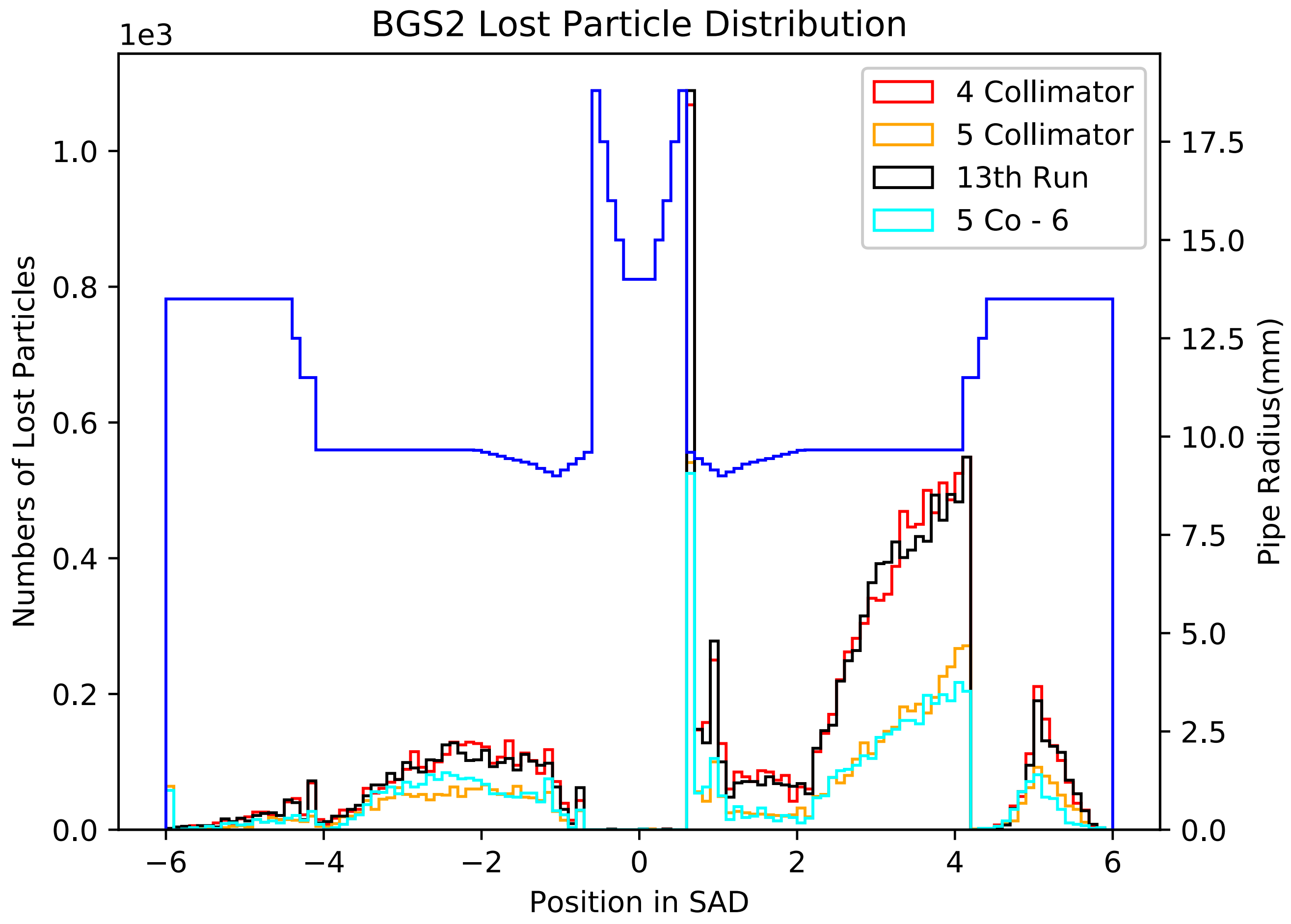
Update of Normalization Factor - 1

In Previous Study, we assume that all regions contribute the same to the lost in the IR with the first 200m.

	200m	Whole Ring
N. Generated	94305	5434566
N. Lost in IR	13387	18887
R. Lost in IR	0.142	0.00348
NF w/o dist changing	1	0.0245

Add One More Collimator - Position

- Red Line and Black Line are different runs with 4 Collimator Sets.
- Orange Line shows one more collimator located at -30m.
- Aqua Line shows one more collimator located at -6m.
- Far is safe. Chose -31m.



Conclusion of this initial study

- Add one more set of collimator after the last bending magnet can help cut down the lost within the IR
- For now, -30.92m could be one choice.
- However, this collimator here must be thicker than others.
- For now, 10cm Copper + 4cm Tungsten seems to be Ok.
- Initial Results, more study need to be done in future.
- No Neutrons survive at -6m.
- Other issues, including heat deposition, photons hitting the magnets, instability of the beam, other particles might come out from the collimator, etc., would be done in future.

Collimators	Hit Density	TID	NIEL
4 Co	36.8372	39901.139	9.65e+13
5 Co	7.797	8354.393	2.02e+13
Ratio	4.72	4.77	4.77

Improve Vacuum & Others

	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)	NIEL ($n_{eq} \cdot cm^{-2} \cdot yr^{-1}$)	Ratio (How much times lower)
Original Results	368.372	399013.39	965.0×10^{12}	1
Fix Lost Ratio	9.025	9775.78	23.6×10^{12}	40.8
Vacuum 10 times better	0.9025	977.578	2.36×10^{12}	408(*10)
Add 1 More Collimator	0.1911	204.94	0.5×10^{12}	1946.16(*4.77)

Combine Results - Updated

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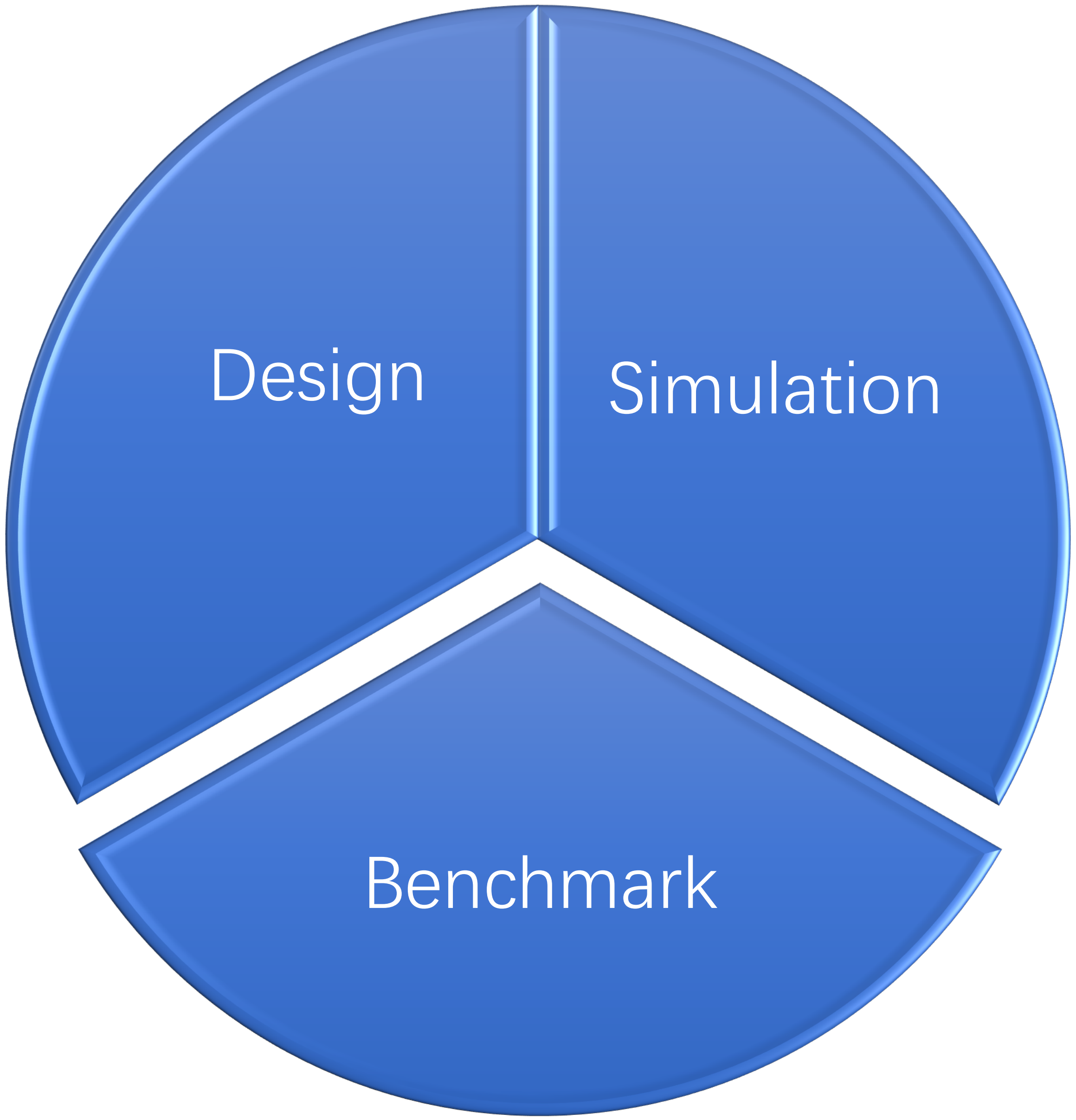
Synchrotron Radiation	0.026	15.65	
Radiative Bhabha	0.34	592.66	1.44×10^{12}
Beam Gas	0.9025	977.578	2.36×10^{12}
Beam Thermal Photon	0.32	318.12	0.75×10^{12}
Total	3.8485	2495.328	5.66×10^{12}

What we have done and what we haven’t

Effects	Beam BG	Photon BG
Touschek	?	-
Beam Gas Coulomb	To Do	To Do
Beam Gas Brem	Doing	To Do
Beam Thermal Photon	Doing	To Do
SR	-	Done with CDR
RBB	Done with CDR	To Do
BS	Done with CDR	Done with CDR


Design
Simulation
Benchmark

Benchmark - Motivation

- 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…

What can be learnt from BEPCII/BESIII

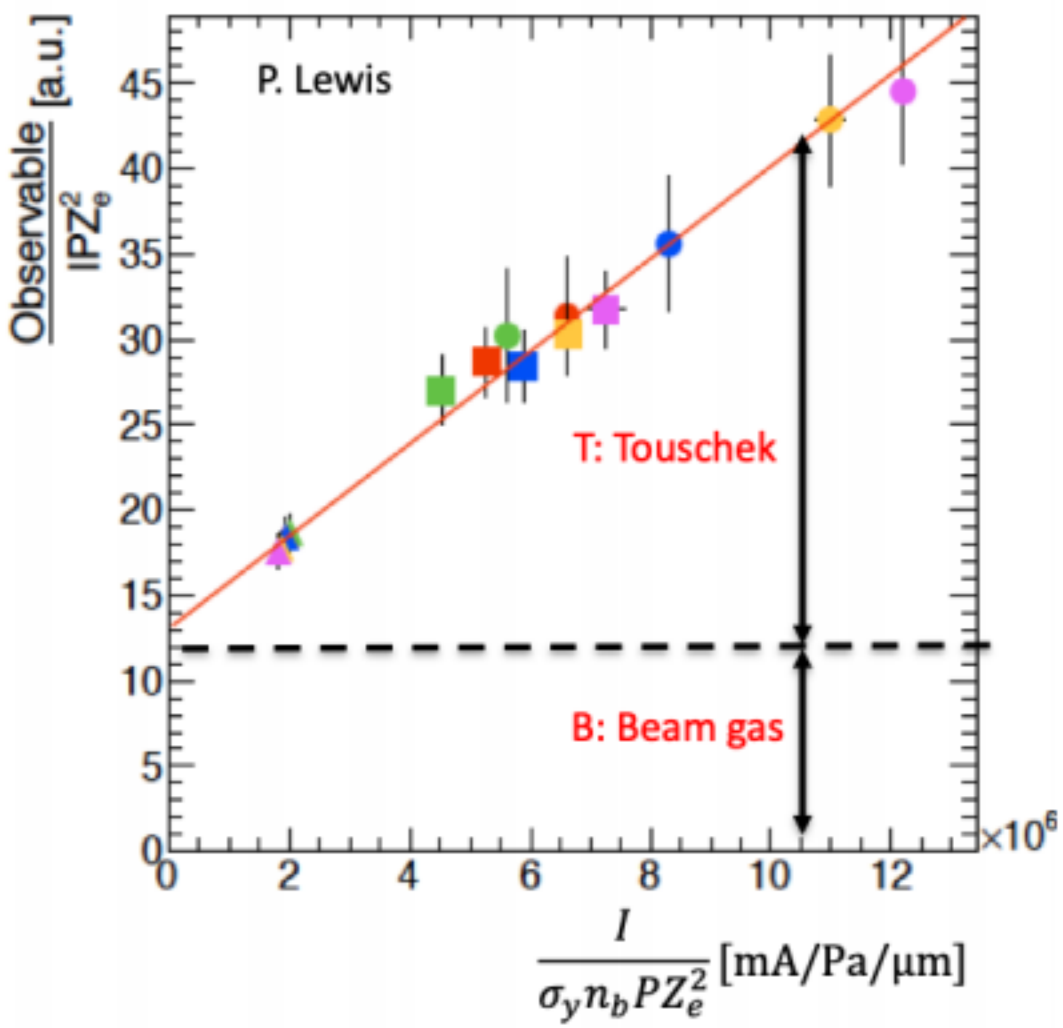
- Basic Principles
- Single beam mode: three dominant contributions from Touschek, beam-gas and electronics noise & cosmic rays.
- $O_{single} = O_{tous} + O_{gas} + O_{noise+\mu} =$
$$S_t \cdot D(\sigma_{x'}) \cdot \frac{I_t \cdot I_b}{\sigma_x \sigma_y \sigma_z} + S_g \cdot I_t \cdot P(I_t) + S_e$$
- Double beam mode: additional contributions from luminosity related backgrounds, mainly radiative Bhabha scattering
- $O_{total} = O_{e^+} + O_{e^-} + O_{\mathcal{L}}$

Single Beam Mode

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

- No Beam, measure the backgrounds in detector(EMC, MDC last year) -> S_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

SuperKEKB Plots



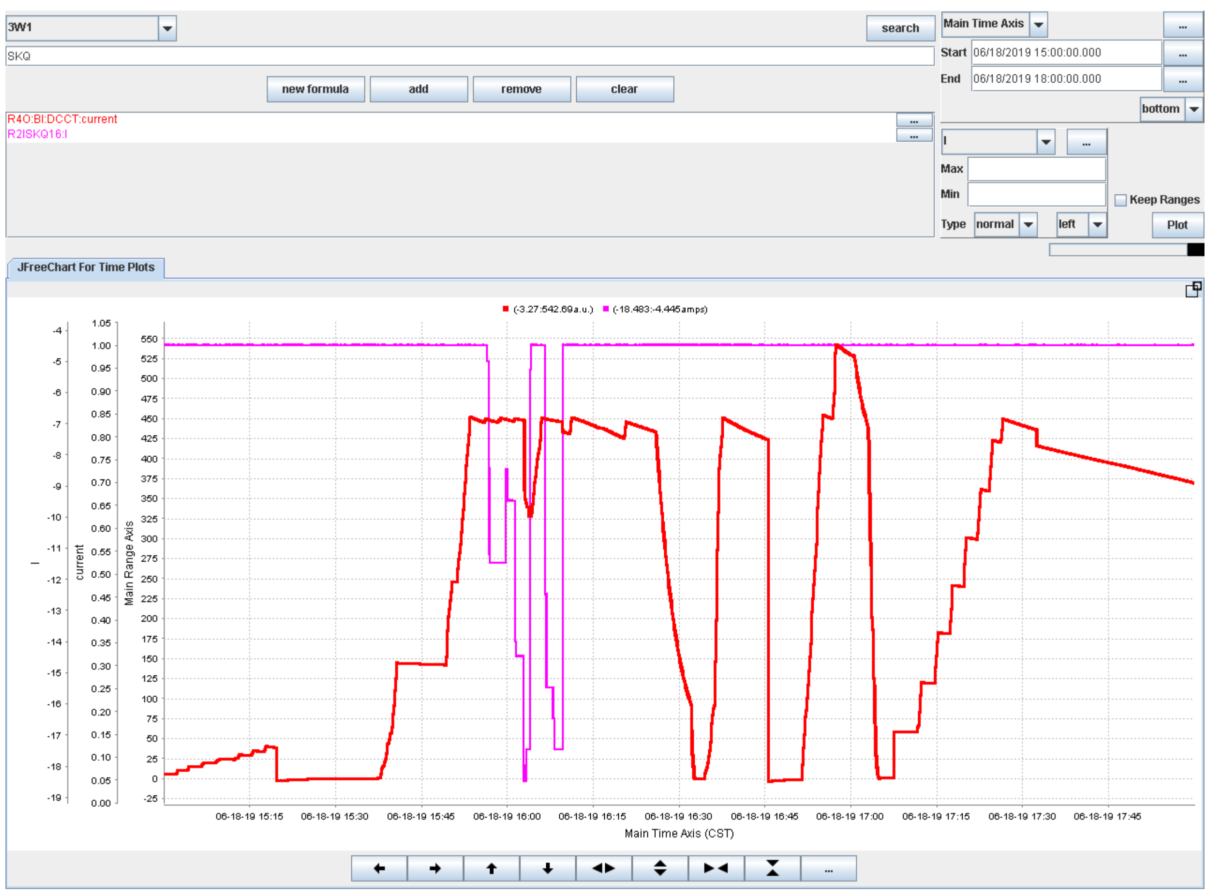
Double Beam Mode

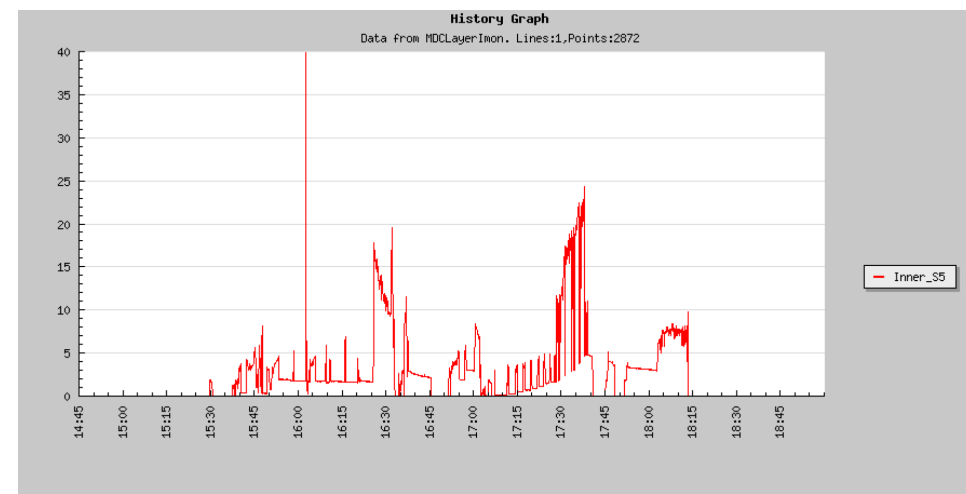
$O_{total} = O_{e^+} + O_{e^-} + O_{\mathcal{L}}$

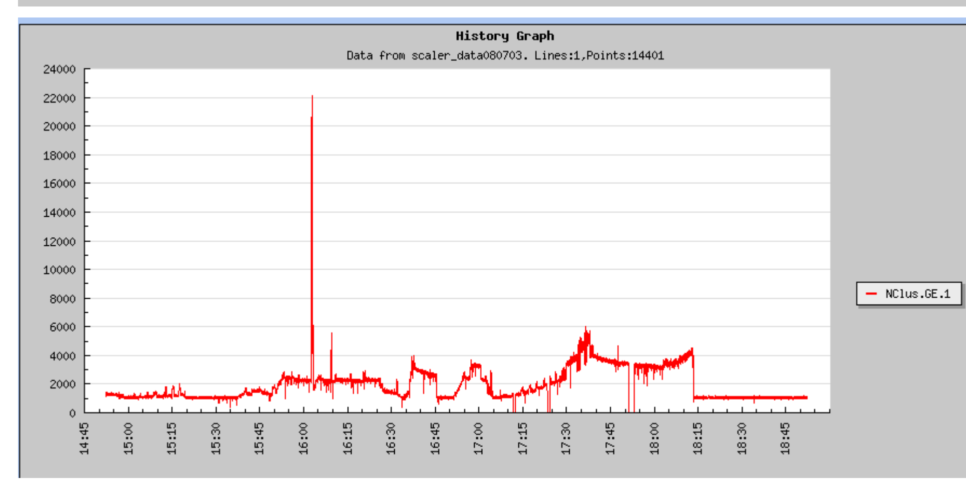
- Fixed beam energy & current, bunch parameters, operating
  - Single e+/e- beam
  - Separate e+ and e- beams
  - Colliding e+ and e- beams

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.

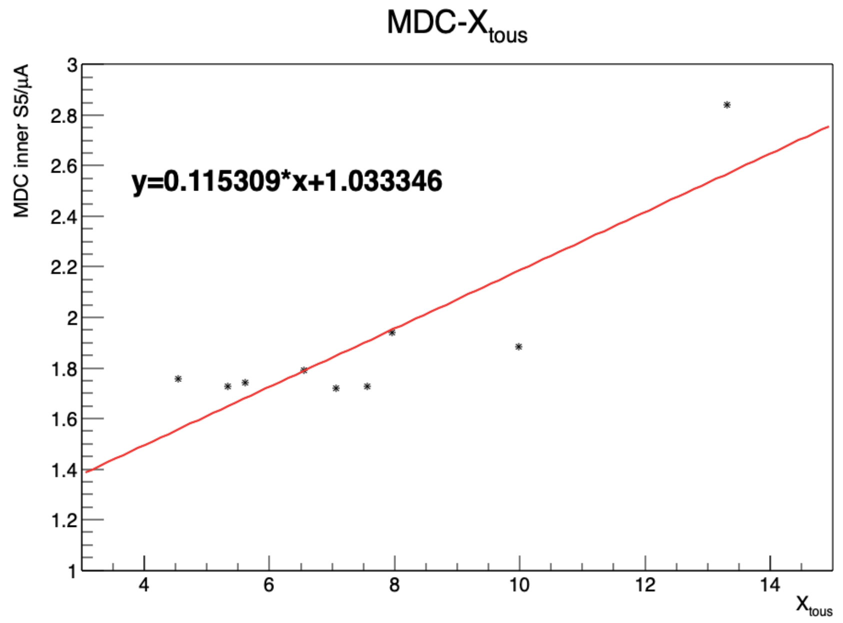


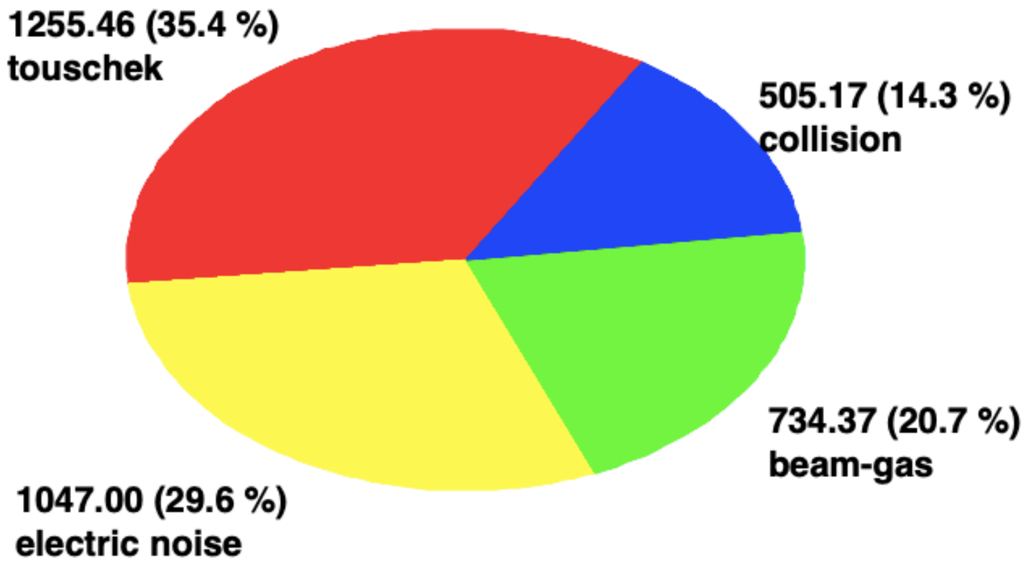




We may need one more round

- 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

Outlook

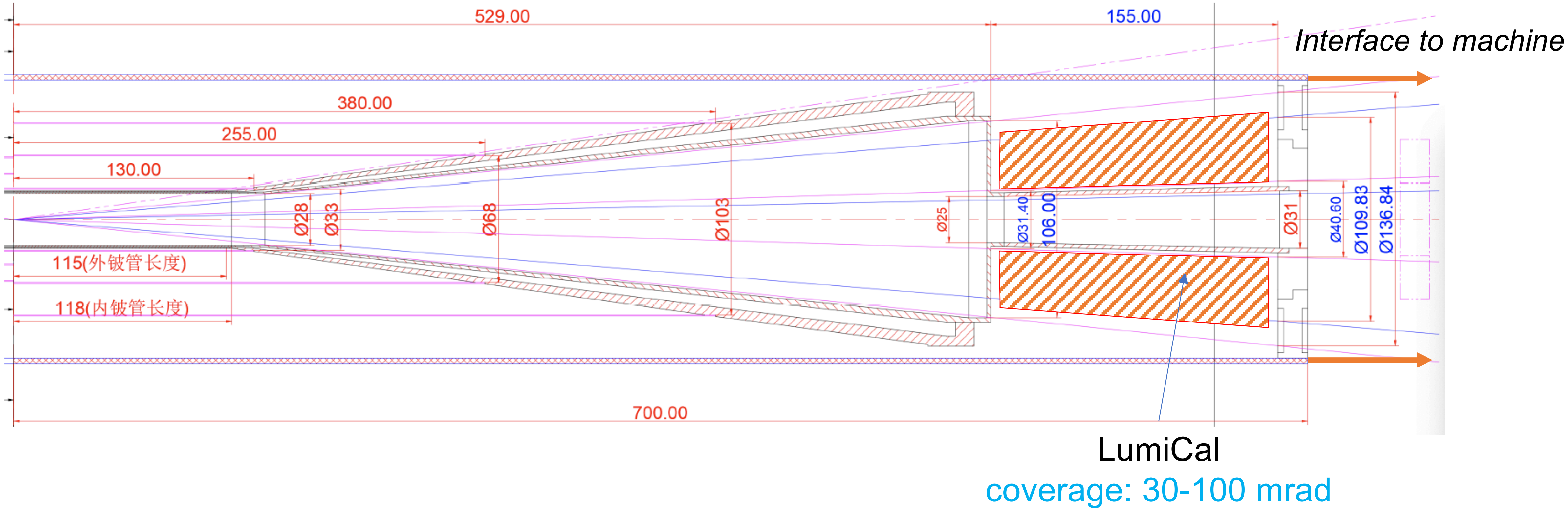
- Improve & Optimize our study
- New Baseline(?). The same design and parameters in all procedures and tools.
- Other Mode. Z?W?
- The impact on other sub detectors / accelerator components in the IR

Thank You

Backup

Old: LumiCal mounted on the Quadrupole and inserted together into the detector, caveat: too much material in front of LumiCal

New: LumiCal with reduced weight mounted on the beampipe instead, together with a supporting structure to mitigate the deformation of the central beryllium beampipe



LumiCal precision requirements/performance being re-evaluated

Mechanical design including beampipe cooling structure ongoing …

Radiation backgrounds to be re-estimated (increased backscattering into the tracking volume)

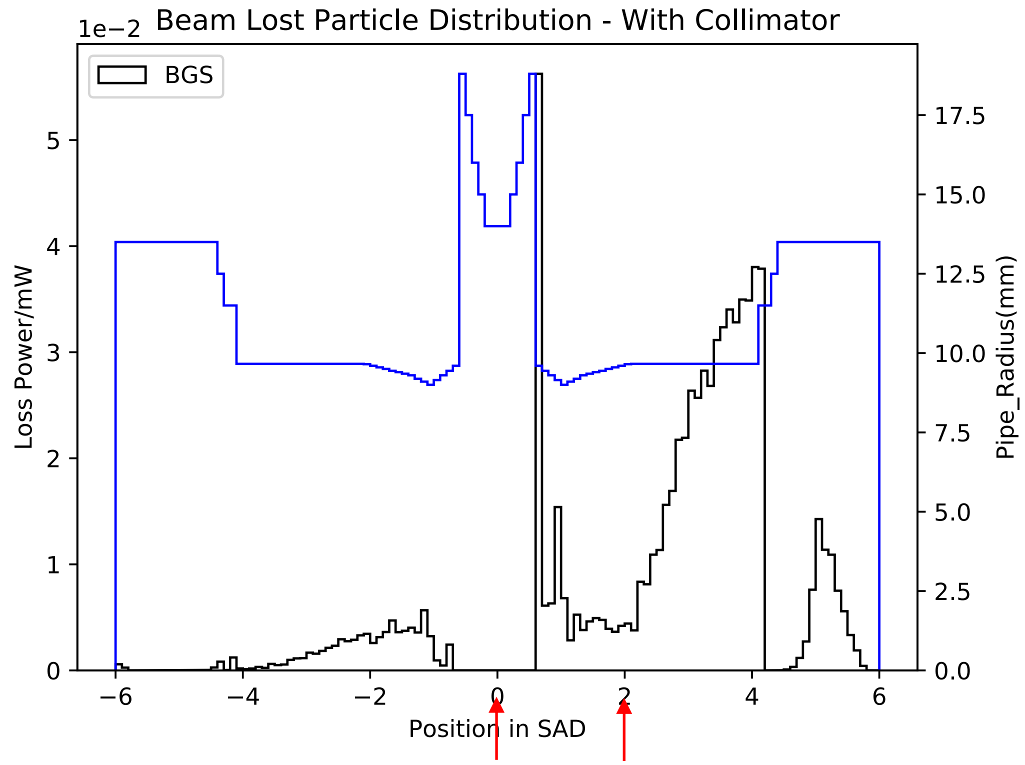
Normalization Factor

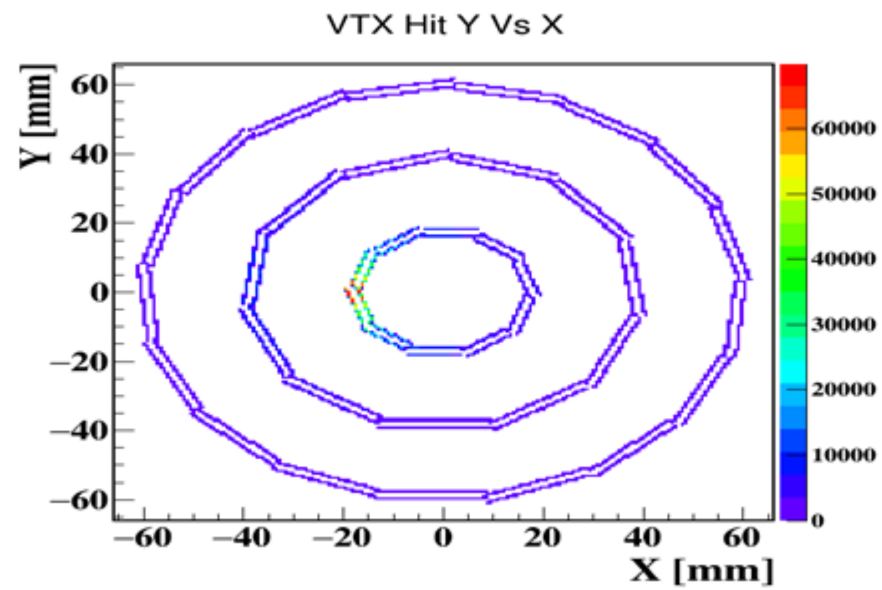
Length:	Generated	Lost in IR
0~1000	530211	25721
1000~2000	536228	26953
2000~3000	558359	6807
3000~4000	540082	4460
4000~5000	539904	3827
5000~6000	539905	1180
6000~7000	539905	3370
7000~8000	539905	3189
8000~9000	558359	1172
9000~10000	540067	2834
Whole Ring	5434566	18887

Update of Normalization Factor

	Beam Gas	Beam Thermal Photon
N. Generated in 200m	94305	94305
N. Lost in IR with 200m	13387	4647
R. Lost in IR with 200m	0.142	0.0492
N. Lost before 2m with 200m	5117	249
R. Lost before 2m with 200m	0.0543	0.00264
N. Generated in WR	5434566	5434566
N. Lost in IR with WR	18887	36599
R. Lost in IR with WR	0.00348	0.00673
N. Lost before 2m with WR	591	517
R Lost before 2m with WR	0.00011	9.513e-5
NF w/o dist changing	0.0245	0.137
NF w/ dist changing	0.002	0.036

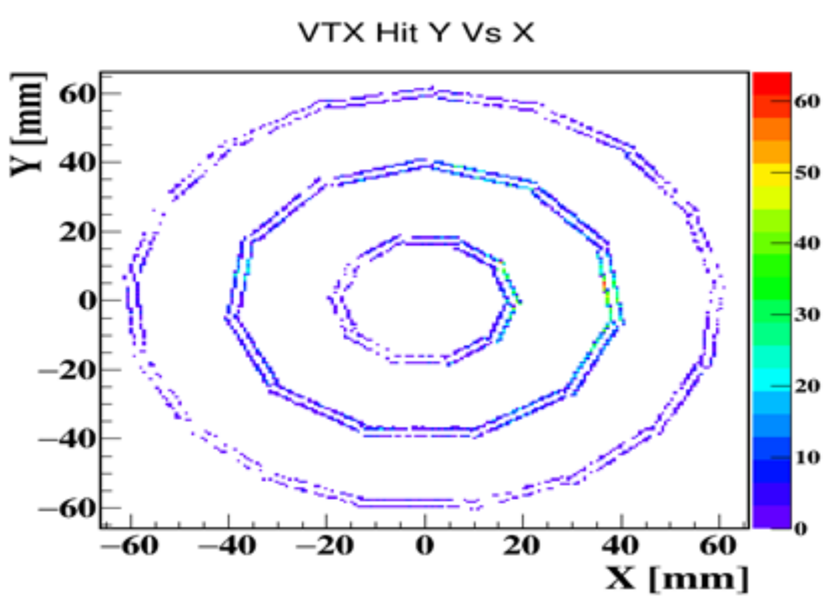
Reshape the lost distribution

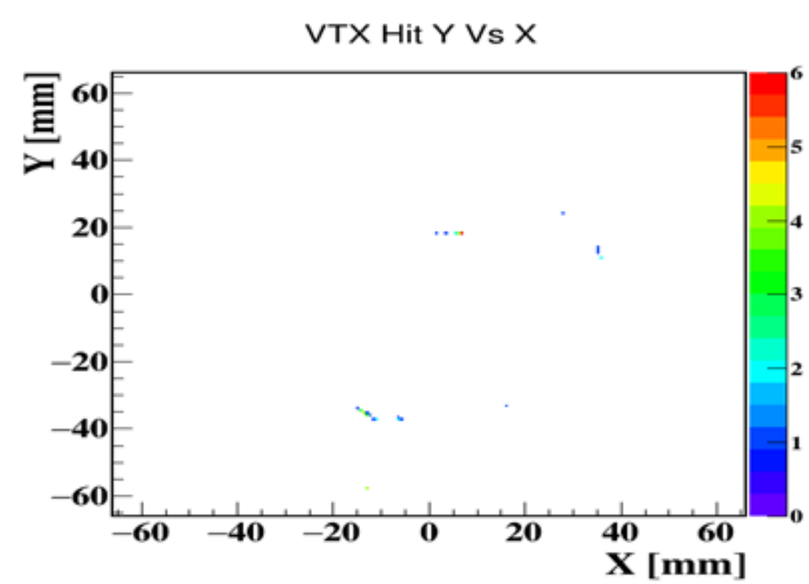




Z:-6~0m

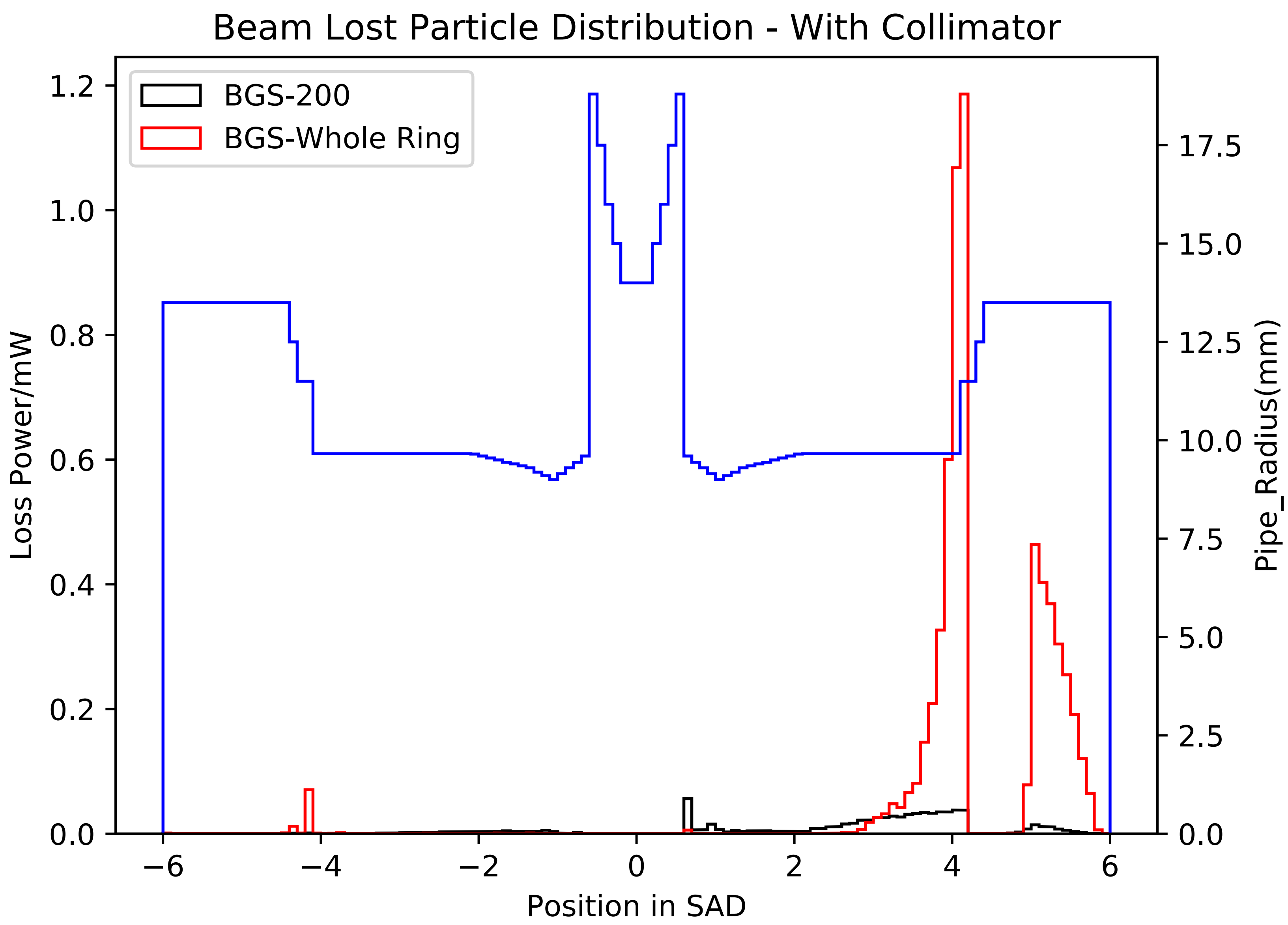
Z:0~2m





Z:2~6m

Reshape the lost distribution



Update of Normalization Factor - 2

	200m	Whole Ring
N. Generated	94305	5434566
N. Lost in IR	13387	18887
R. Lost in IR	0.142	0.00348
NF w/o dist changing	1	0.0245
N. Lost before 2m	5117	591
R Lost before 2m	0.0543	0.00011
NF w/ dist changing	1	0.002

问题

- 1 几何落实不统一（加速器设计，探测器设计，更新）
- 2 如何验证模拟的准确性，Benchmark？
- 3 最关键的问题，Beam Gas，如何进一步优化？
- 4 其余的光子本底，是没有影响，还是没计算影响？如果是后者，如何研究？
- 5 其余的能散束流本底，问题同上
- 6 其余能量状态的问题？
- 7 外层探测器，甚至是对撞区加速器部件的影响