CEPC MDI Radiation Backgrounds Study

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On Behalf of the CEPC MDI Study Group
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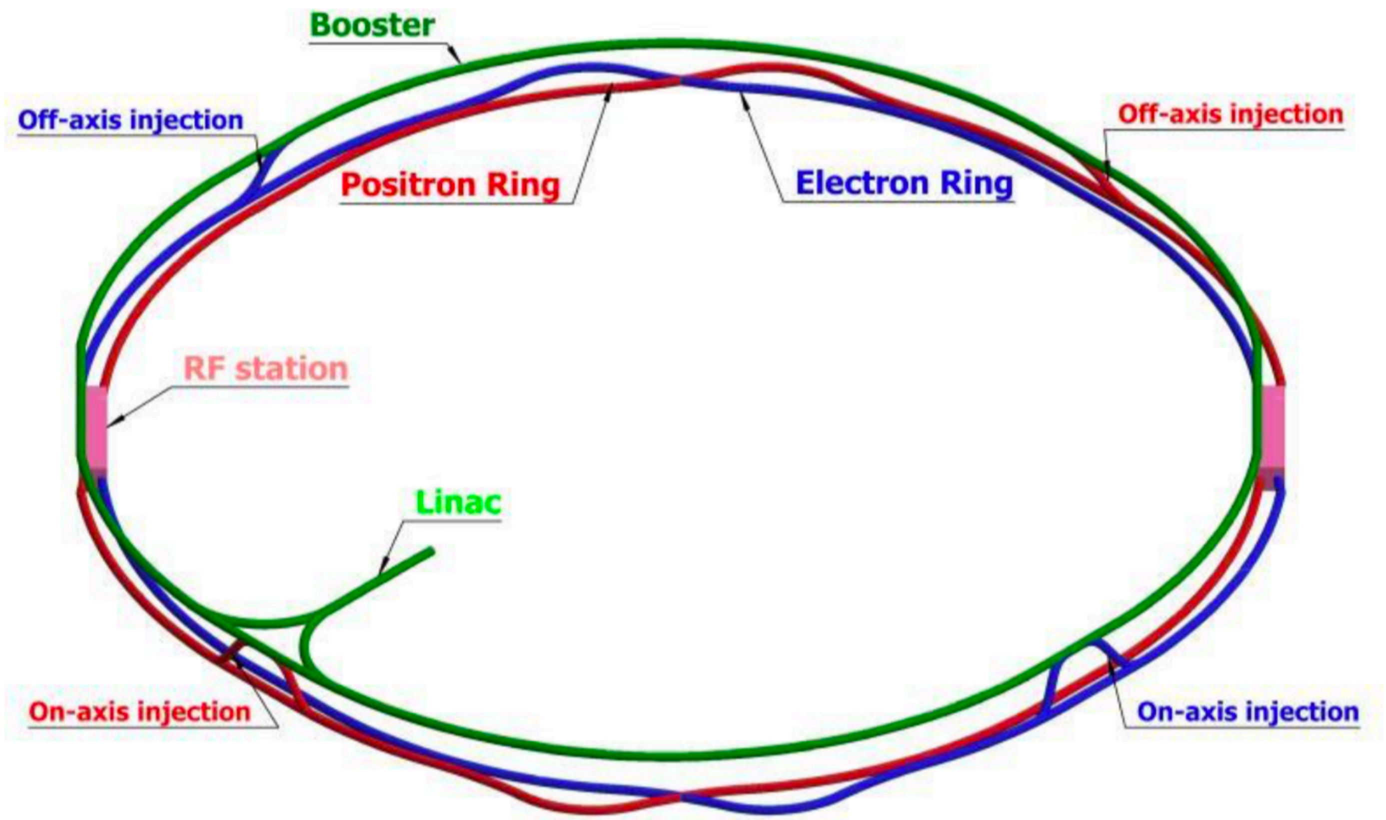
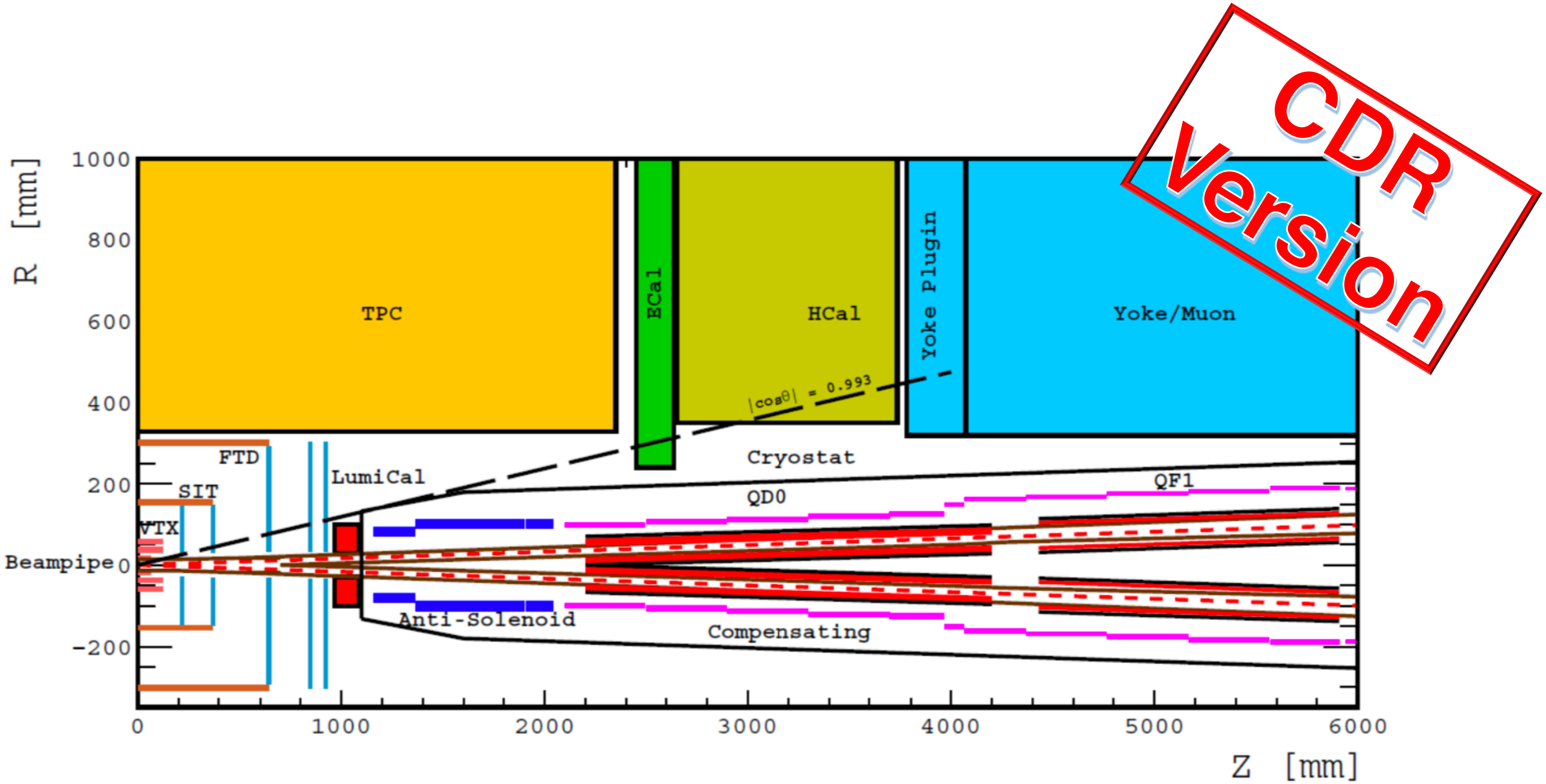
Outline

- Introduction & IR Layout
- Background Study Status in detail
- Summary & Outlook



Interaction Region Layout

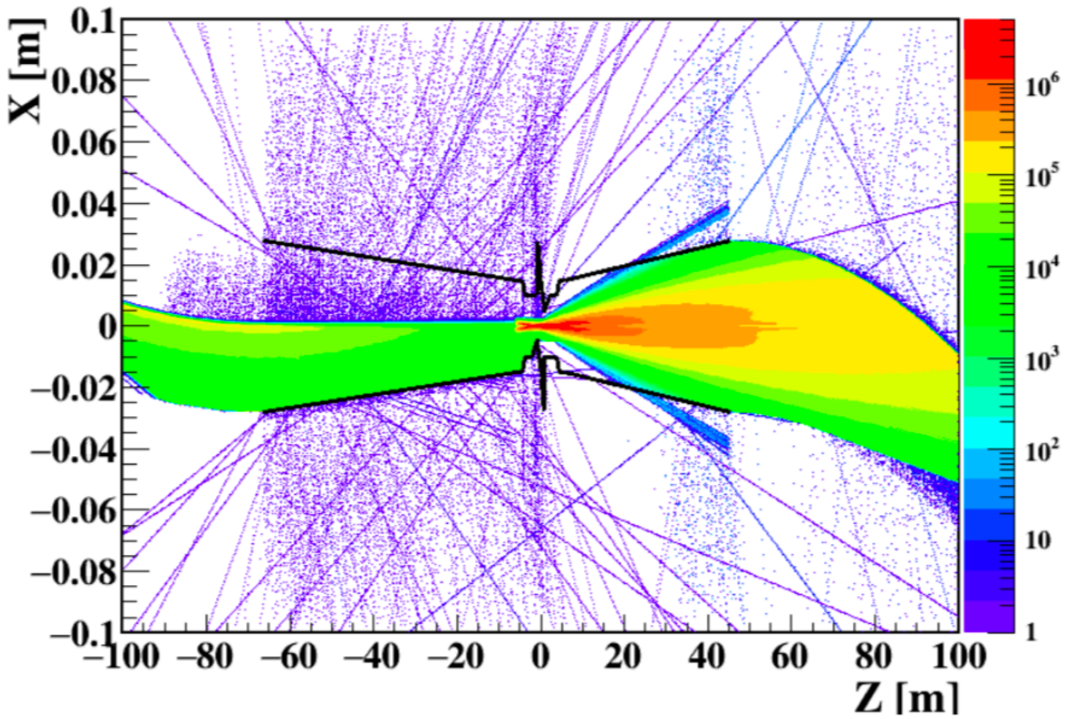


Introduction

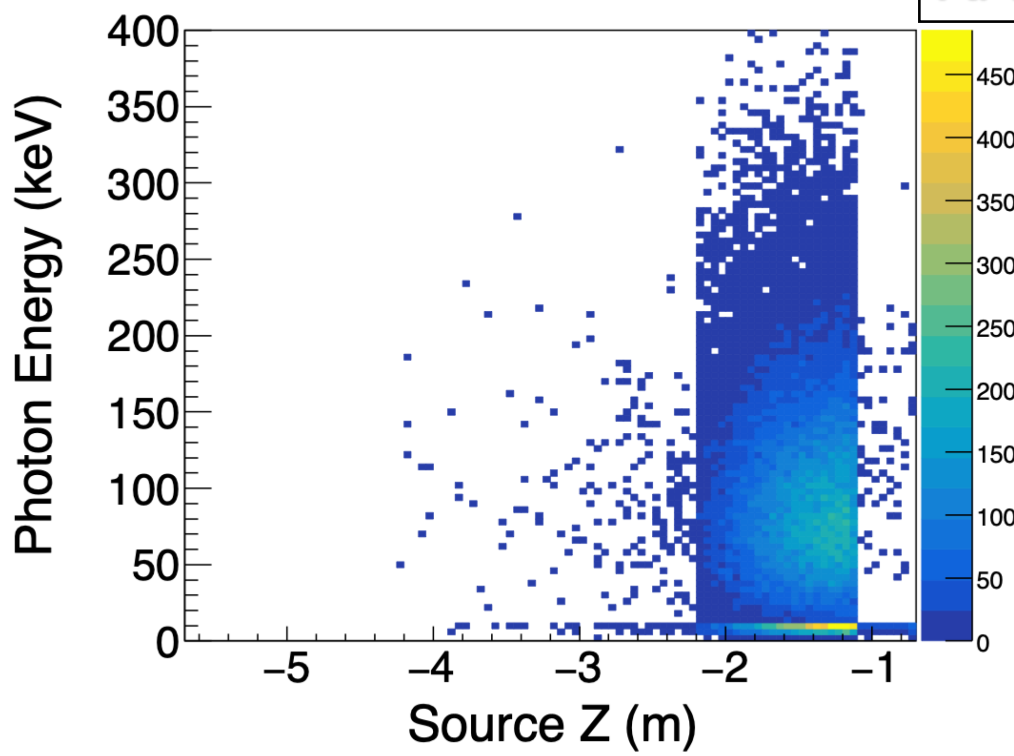
- Backgrounds may impact IR components, especially detectors in several ways, so that they are important inputs to the detecto r(also accelerator) design, such as radiation tolerance, detector occupancy…
- Have to study different sources and types separately:
  - SR
  - Pair Production
  - Off energy beam particles
- Backgrounds Study mainly focus on Higgs Now

Synchrotron Radiation

- Beam bent by magnets would emit synchrotron radiation, sometimes would be critical at circular machines
- Some would hit the detectors(bent by last bending dipole, focusing quadrupoles)
- BDsim used to transport beam particles from the last dipole to the interaction region and record the particles hitting the central beryllium pipe



K. Li



SR Mask

K. Li

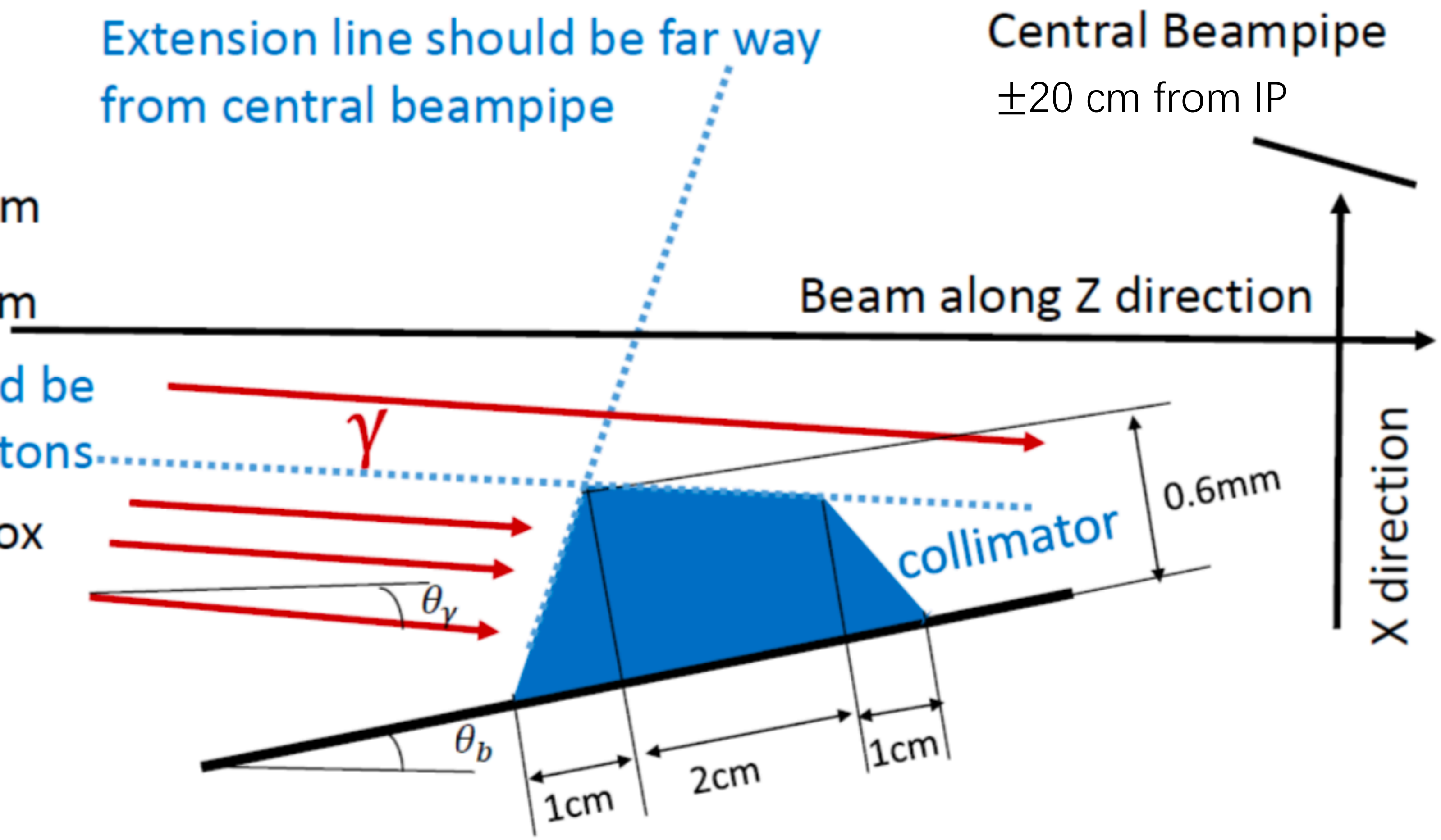
θ_b = 1.17 mrad

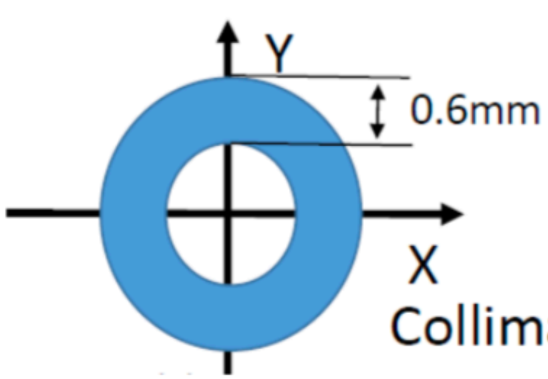
$\theta_\gamma = -127 \pm 7\ \mu$rad at Z=-1.51m

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

Extension line should be parallel with SR photons

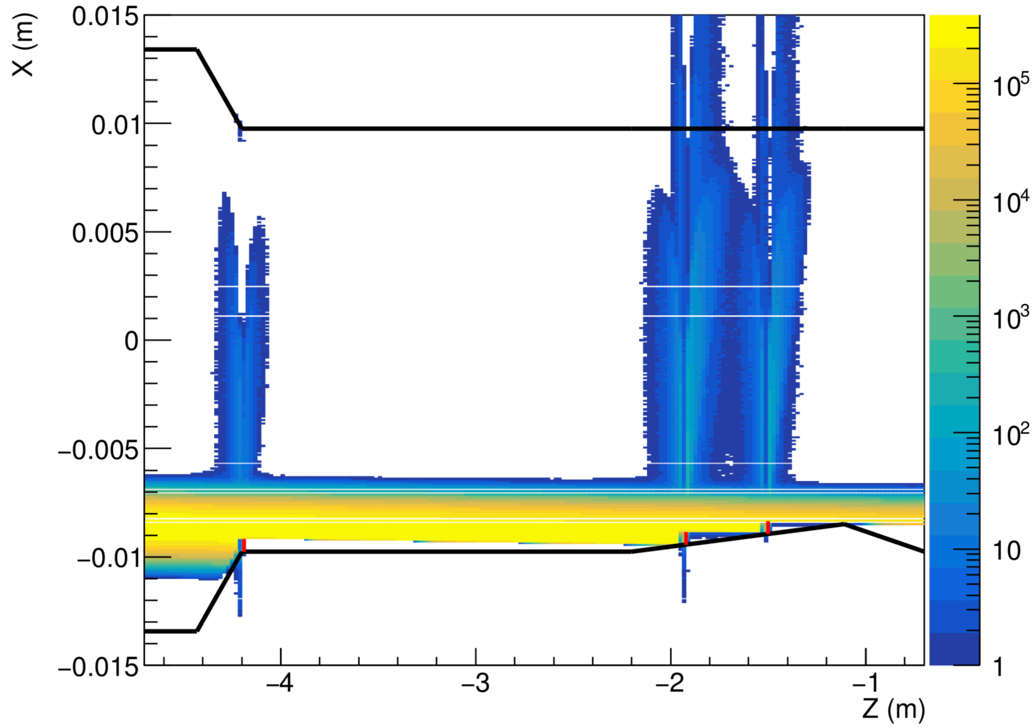
Collimator at Z=-4.2m: just a box

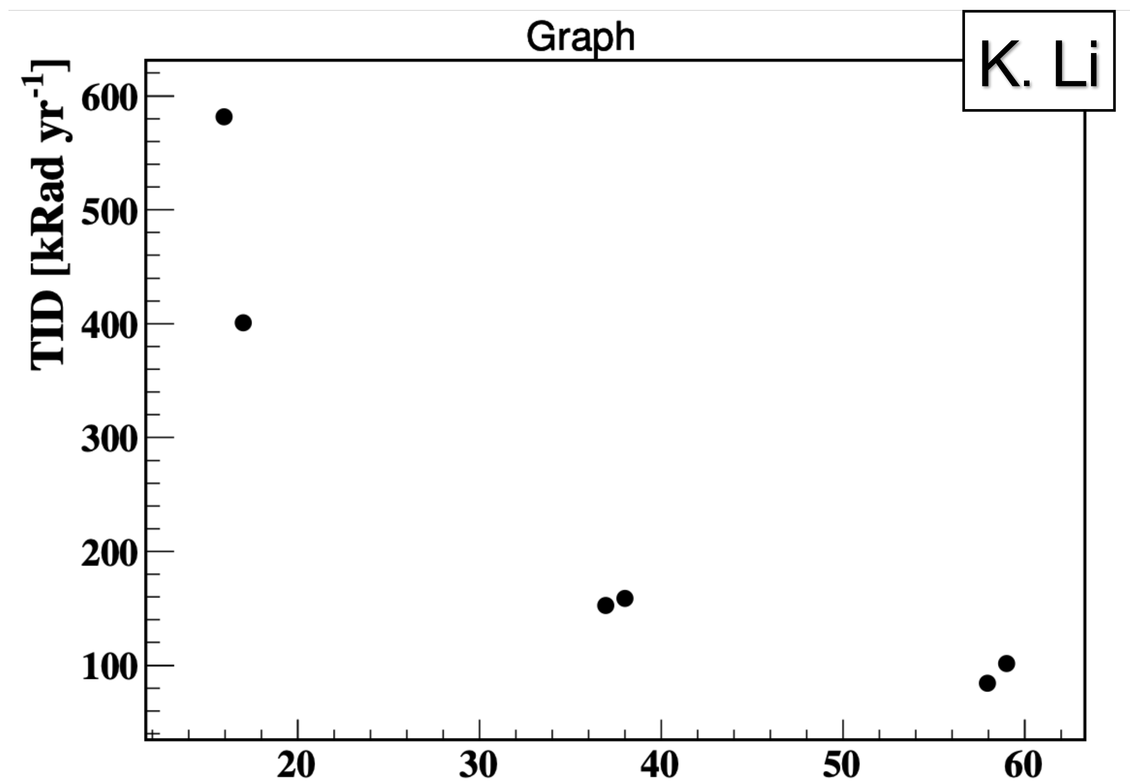


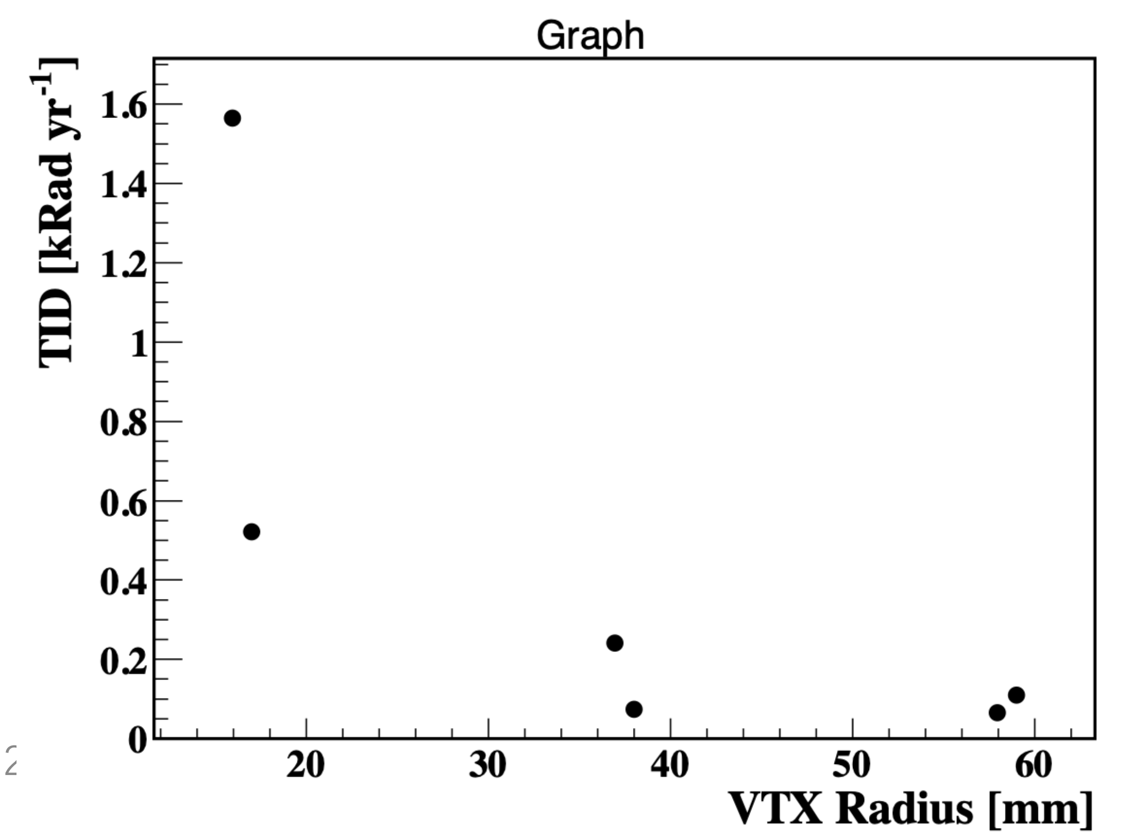


Collimator at X-Y plane: a ring

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.

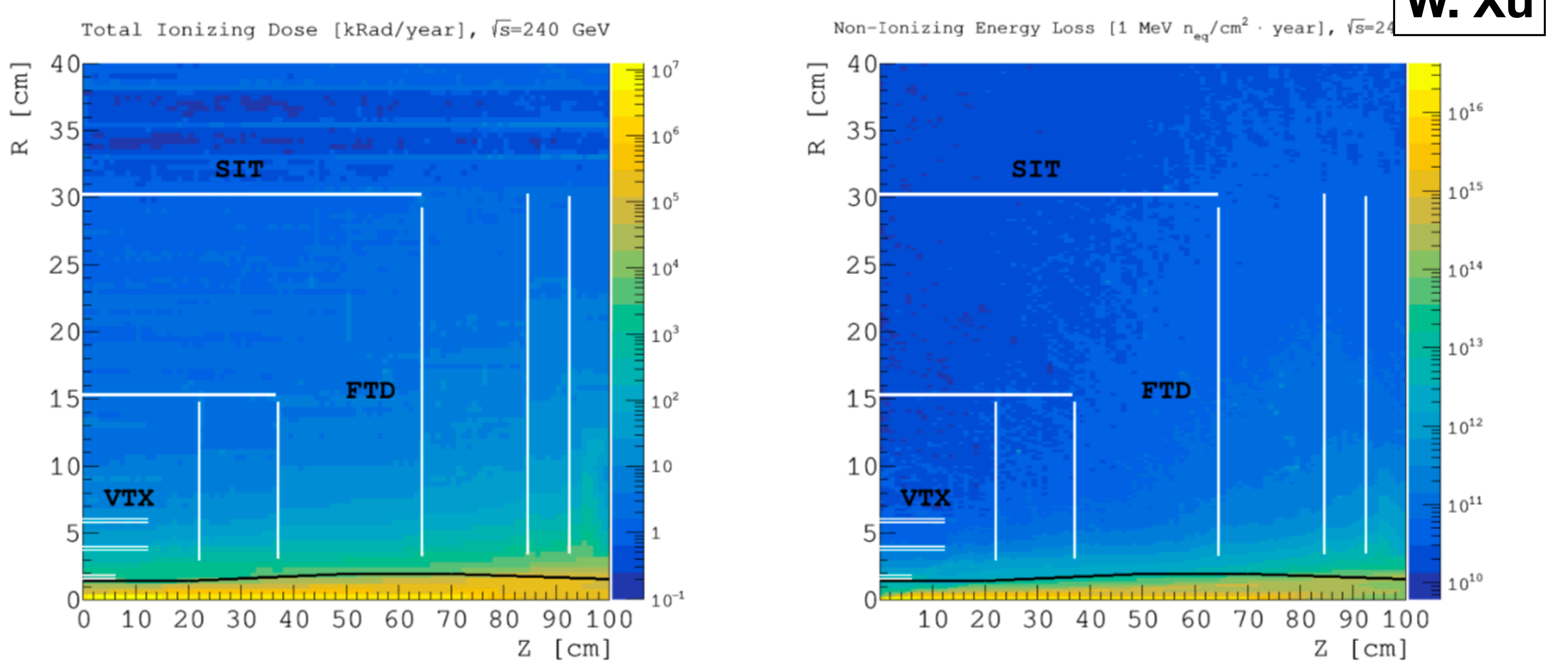
Pair Production

- Charged Particles attract by the opposite beam emit photons(beamstrahlung), followed by an electron-positron pair production.
- Most electrons/positrons are produced with low energies and in the very forward region and can be confined within the beam pipe with a strong detector solenoid; However, a non-negligible amount of electrons/positrons can hit the detector —> radiation backgrounds.
- Using Gienea-pig++ as the generator and implementing the external magnetic field by code updating.

Pair Production

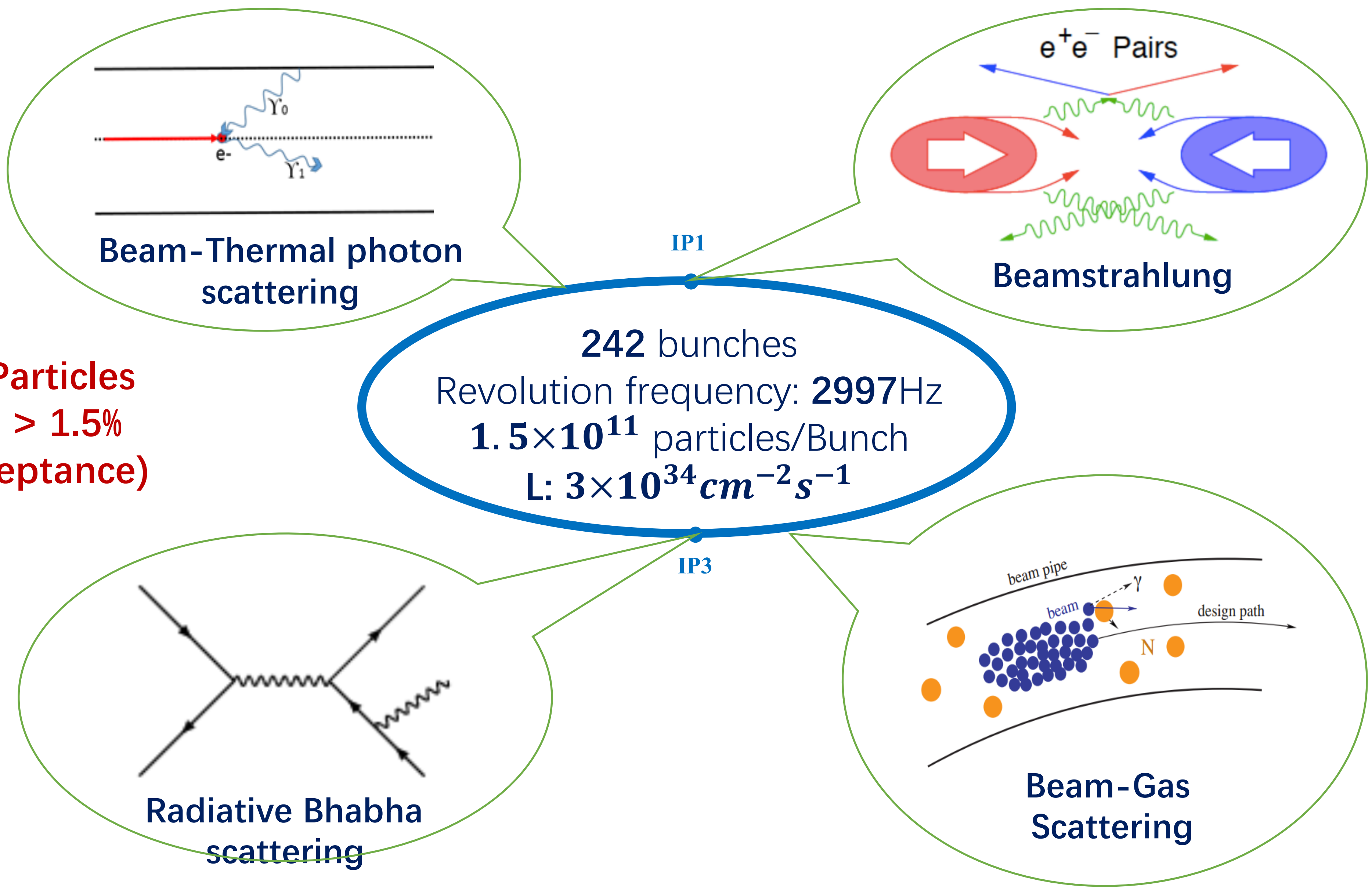
- Using hit density, total ionizing dose(TID), and non-ionizing energy loss(NIEL) to quantify the backgrounds impact.
- Adopted the method ATLAS used(ATL-GEN-2005-001) for background estimation, and applied a safety factor of $\times 10$.

W. Xu



Off Energy Beam

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



CEPC Beam Lifetime

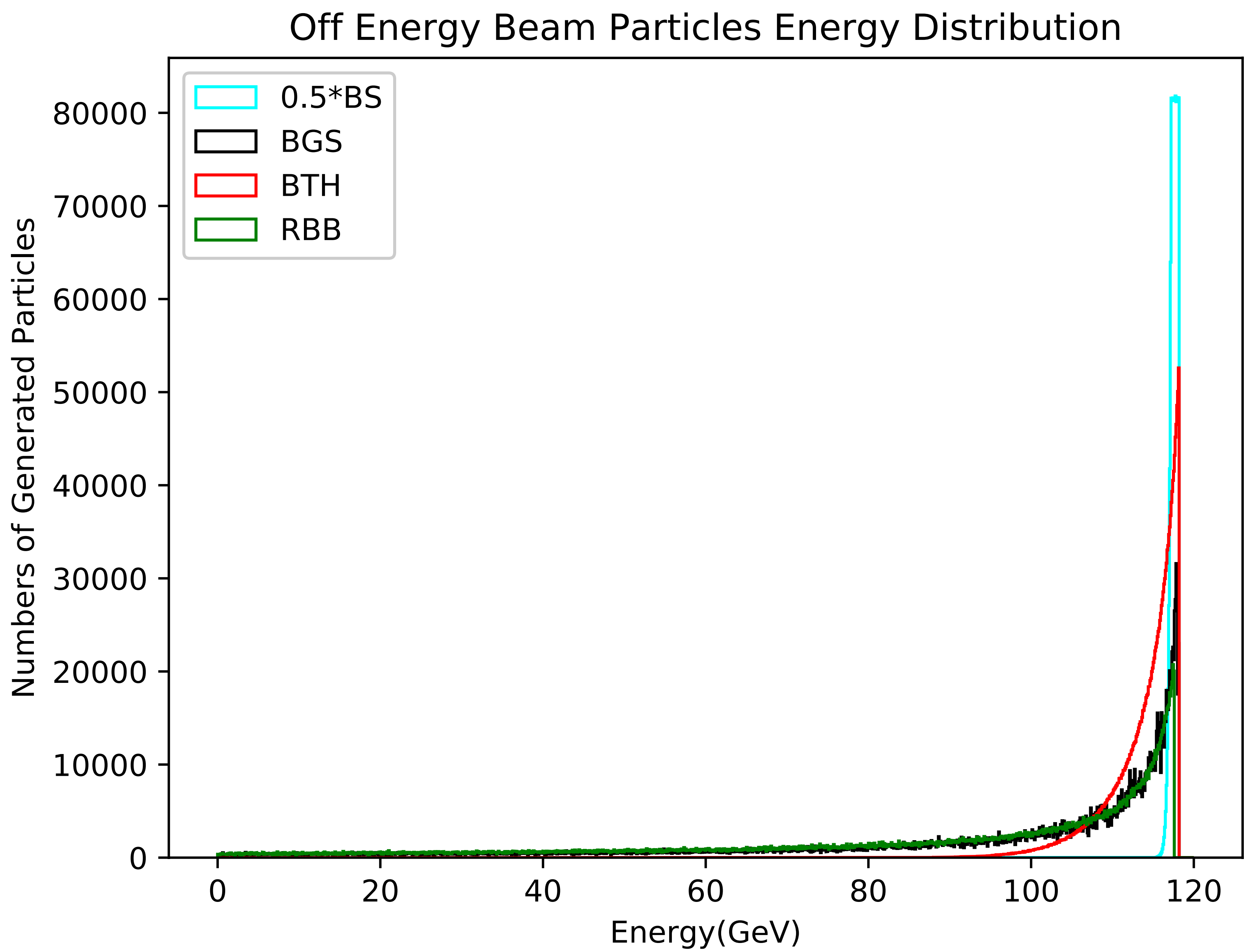
	Beam Lifetime	Others
Quantum effect	>1000 h	
Touschek effect	>1000 h	
Beam Gas Coulomb	>400 h	CO, 10^{-8} Pa
Beam Gas Bremsstrahlung	63.8 h	CO, 10^{-8} Pa
Beam Thermal Photon Scattering	50.7 h	
Radiative bhabha Scattering	74 min	
Beamstrahlung	80 min	

Generators and Tools

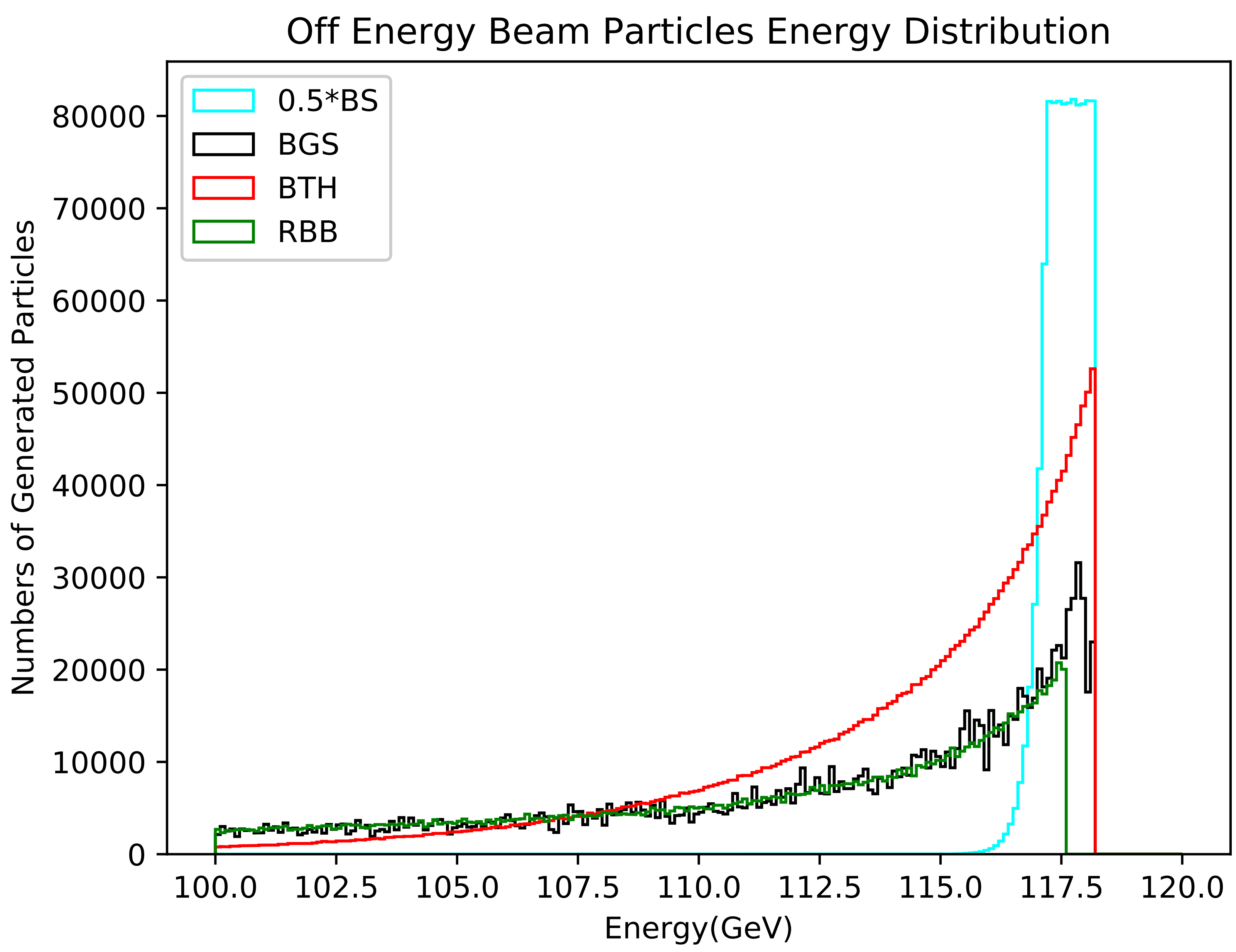
- Off energy particles were generated by several generators, and tracking by SAD in accelerators when necessary. Detector simulation was done by Mokka(Geant4).

Background Type	Generators
Beamstrahlung	PyBS/Guinea-Pig++
Radiative Bhabha	bbbrem/PyRBB
Beam Gas Scattering(inelastic)	PyBGS2
Beam Thermal Photon	PyBTH

Energy Spectrum



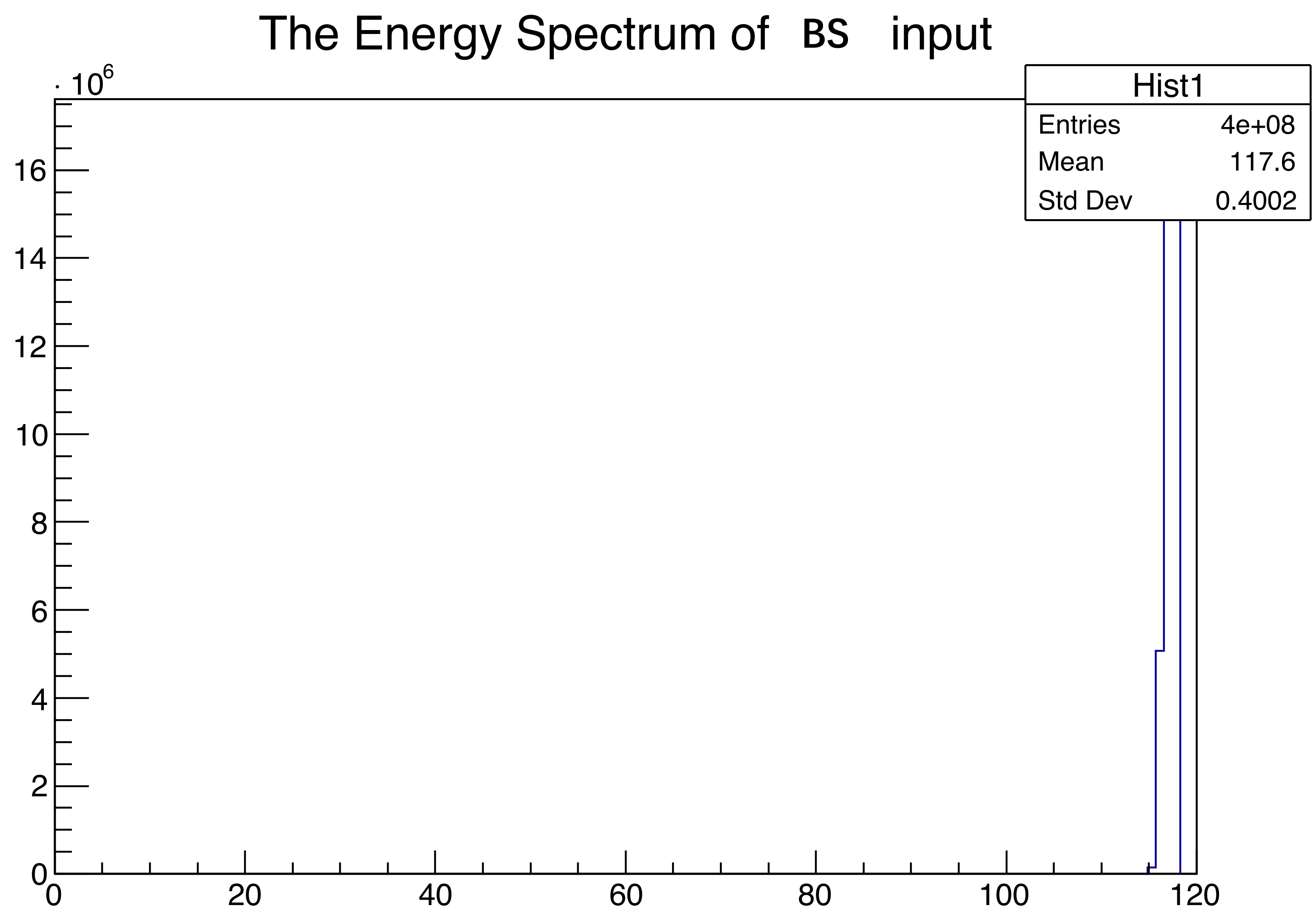
Energy Spectrum



Beamstrahlung

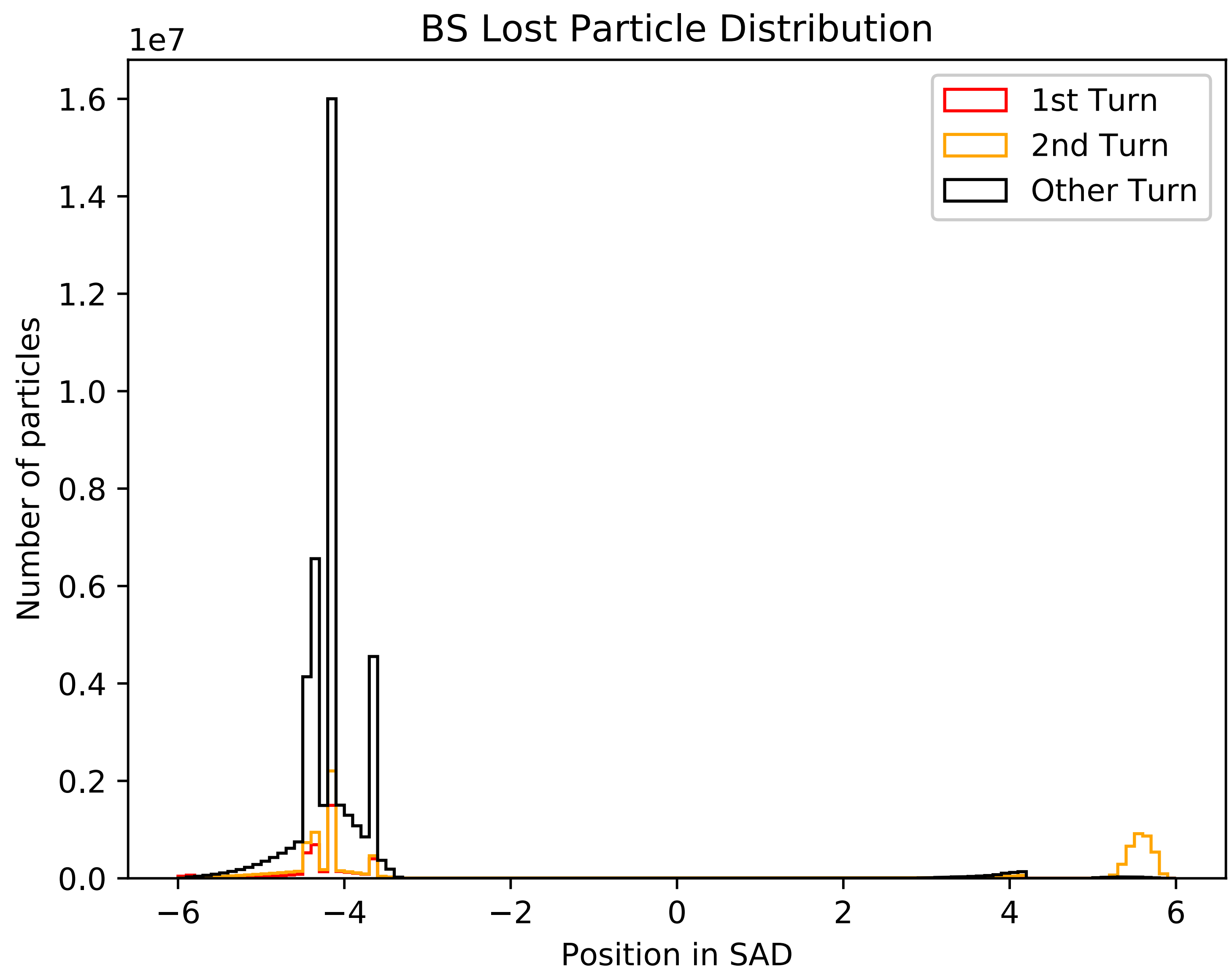
- Beamstrahlung is the radiation background from one beam of charged particles in storage rings or linear colliders caused by its interaction with the electromagnetic field of the other beam
- Generated by formula(PyBS)
  - Code Written by Dr. Yue
- Checked with Guinea-Pig++

Beamstrahlung



- Very narrow range, should be lost after many turns

Beamstrahlung

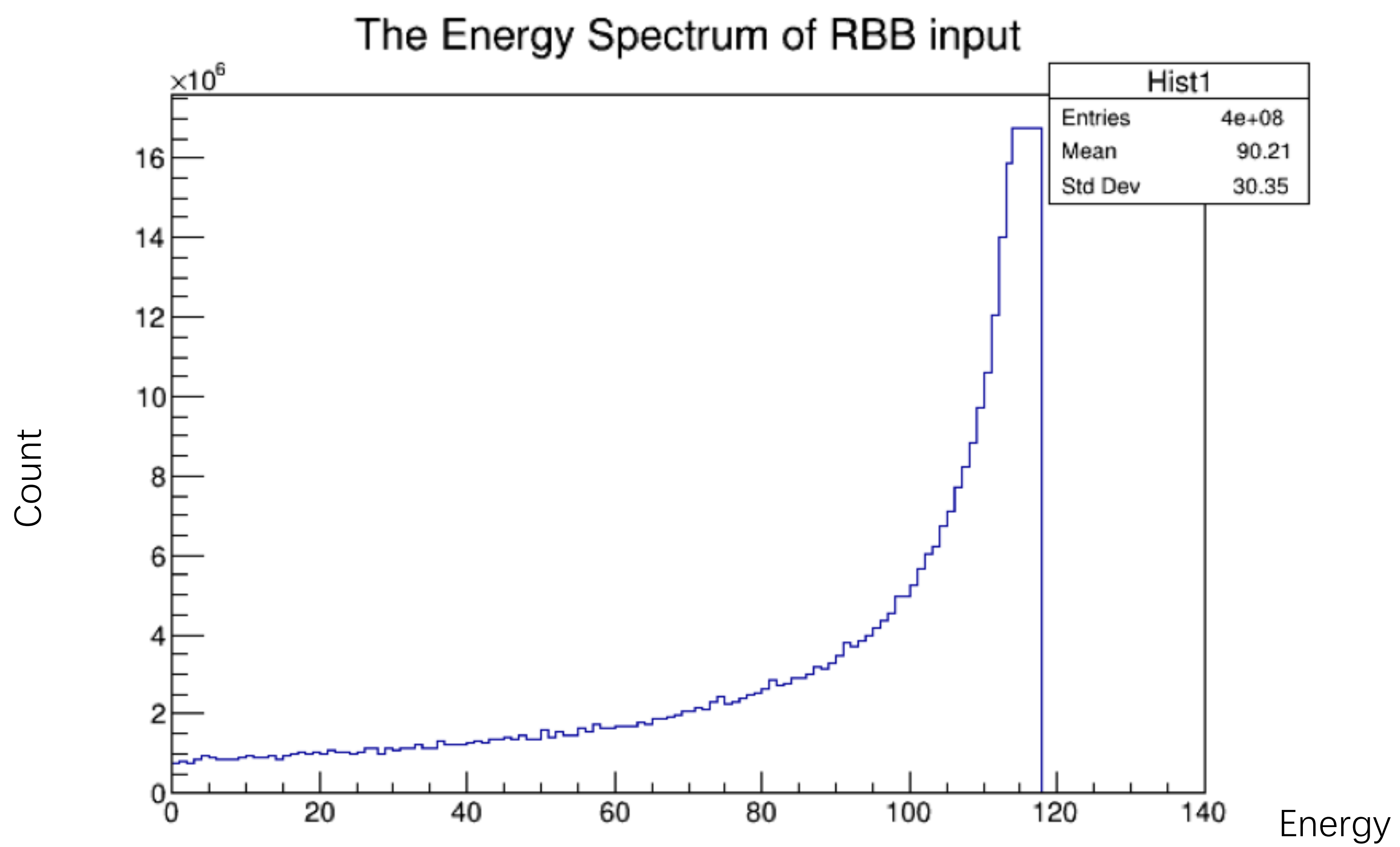


- Other means > 2
- Collimator or mask might be helpful

Radiative Bhabha

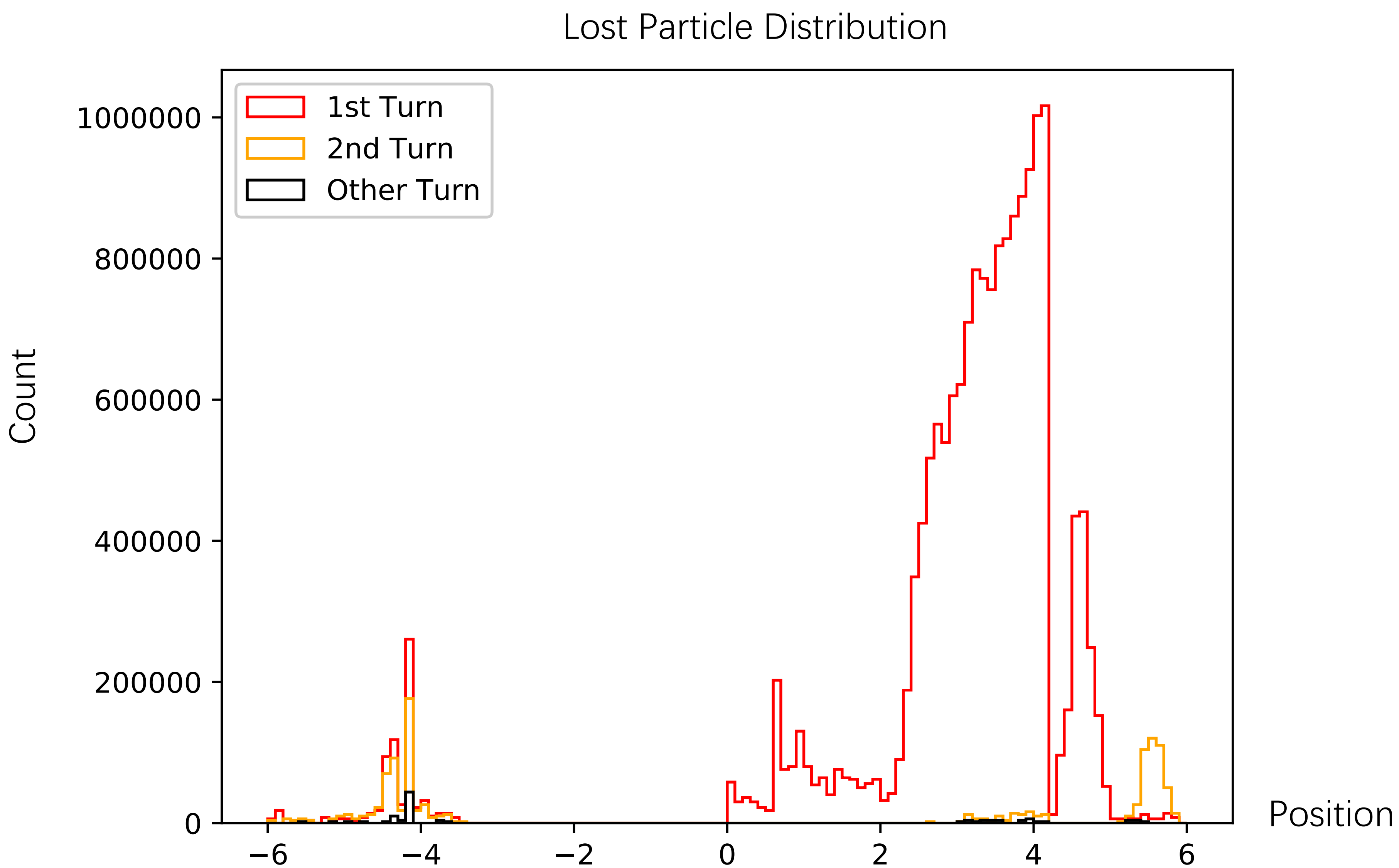
- Radiative bhabha scattering represents the progress that one electron/position interact with the other and emit photons. The electron/position could loss energy, and might become background.
- Generated by bbbrem
- Could also generated by formula(Py_RBB)
  - Code Written by Dr. Yue

Radiative Bhabha



- Wide Range of energy
- Could be expect lost immediately or after many turns

Radiative Bhabha

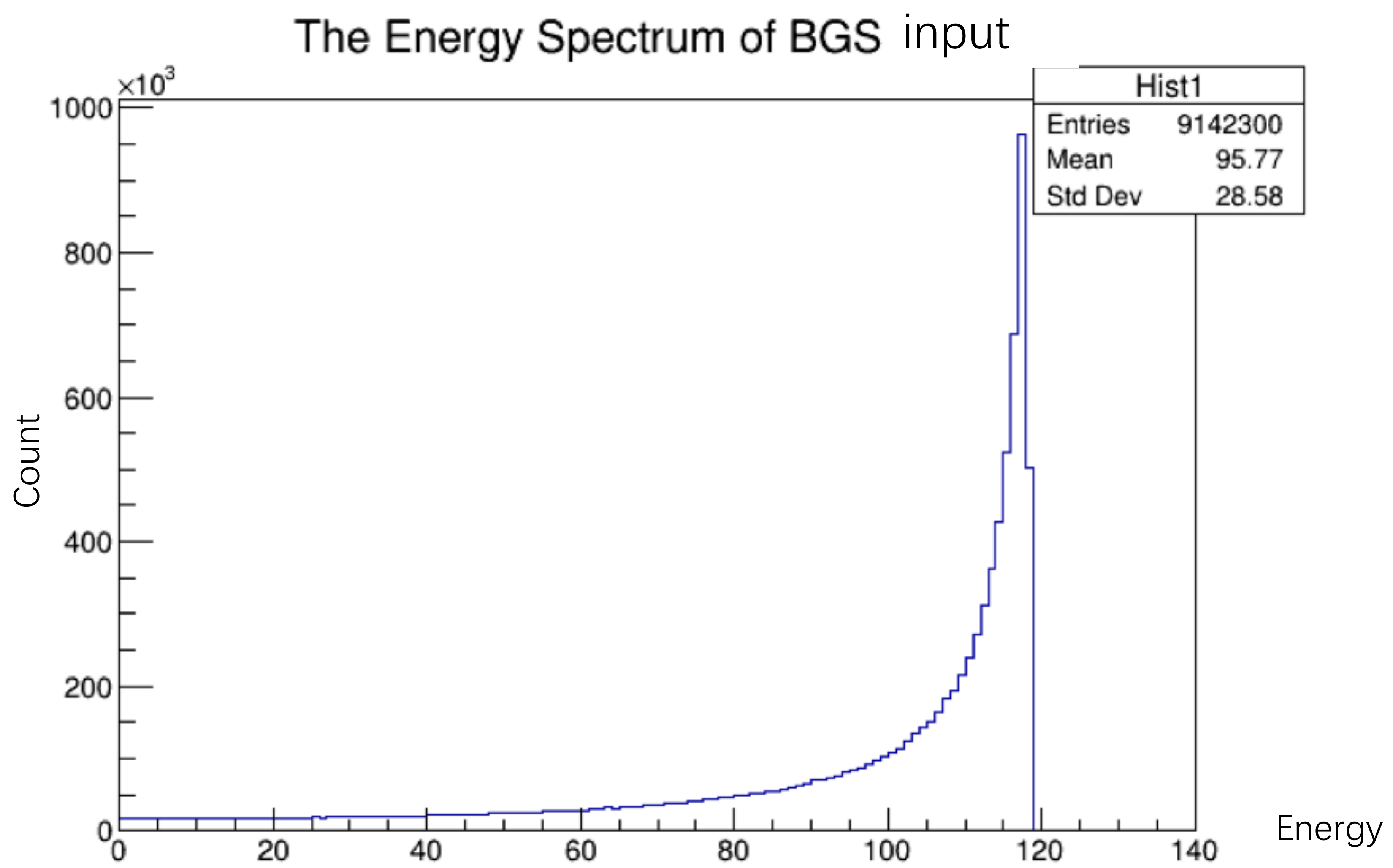


- 1^{st} turn downstream contributes most

Beam Gas

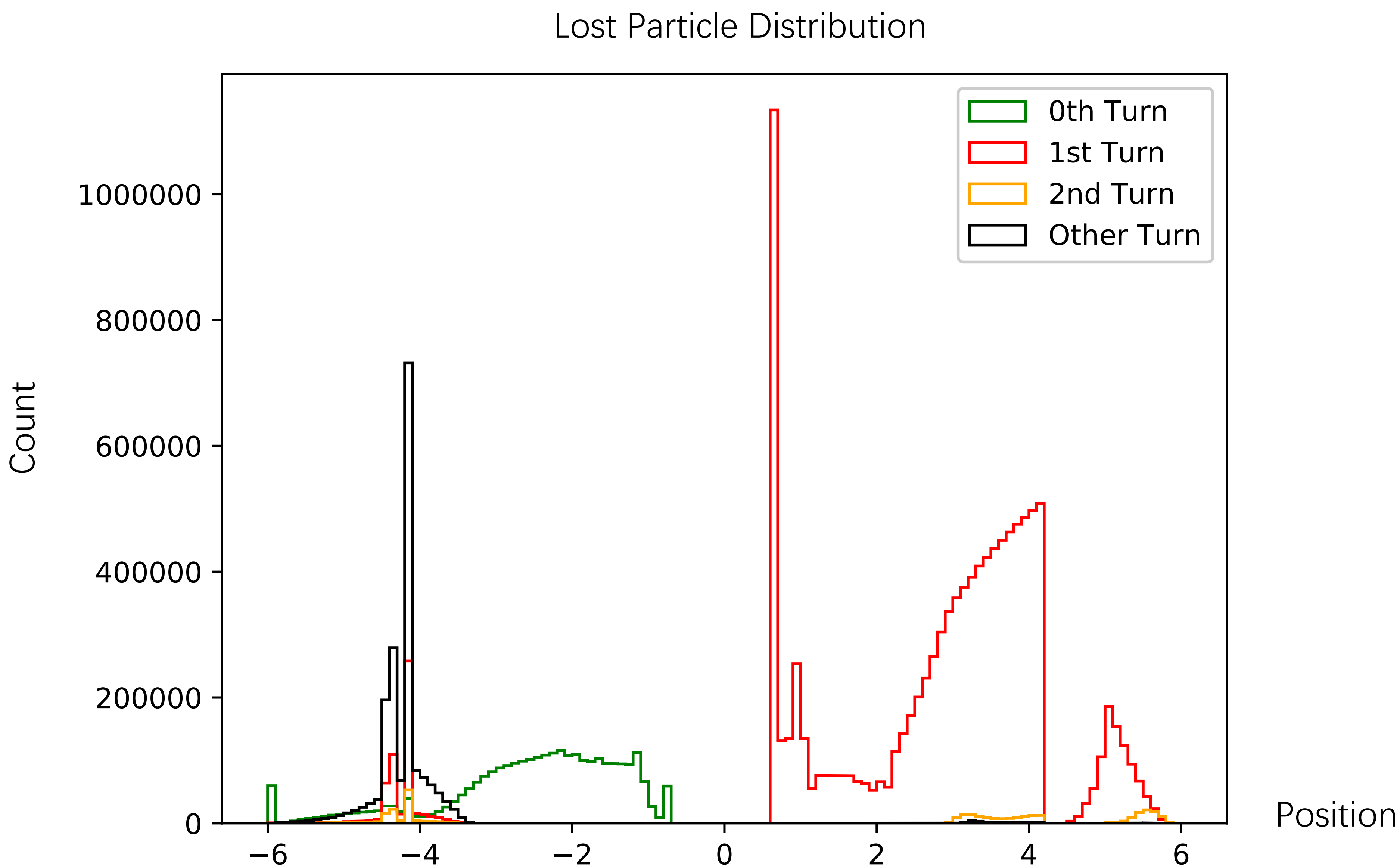
- Beam Particle interact with residual gas
- Beam-Gas Inelastic Scattering:
  - With nuclei
  - With electron
  - σ doesn't relevant with energy, has strong impact on both high and low energy machine
- Generated by PyBGS2
  - Written by Dr. Yue
  - Residual Gas CO, with $10^{-8} Pa$
  - The scattering was generated with 200 meters to the IP
  - Tracking whole ring for many turns

Beam Gas



- Similar to RBB

Beam Gas

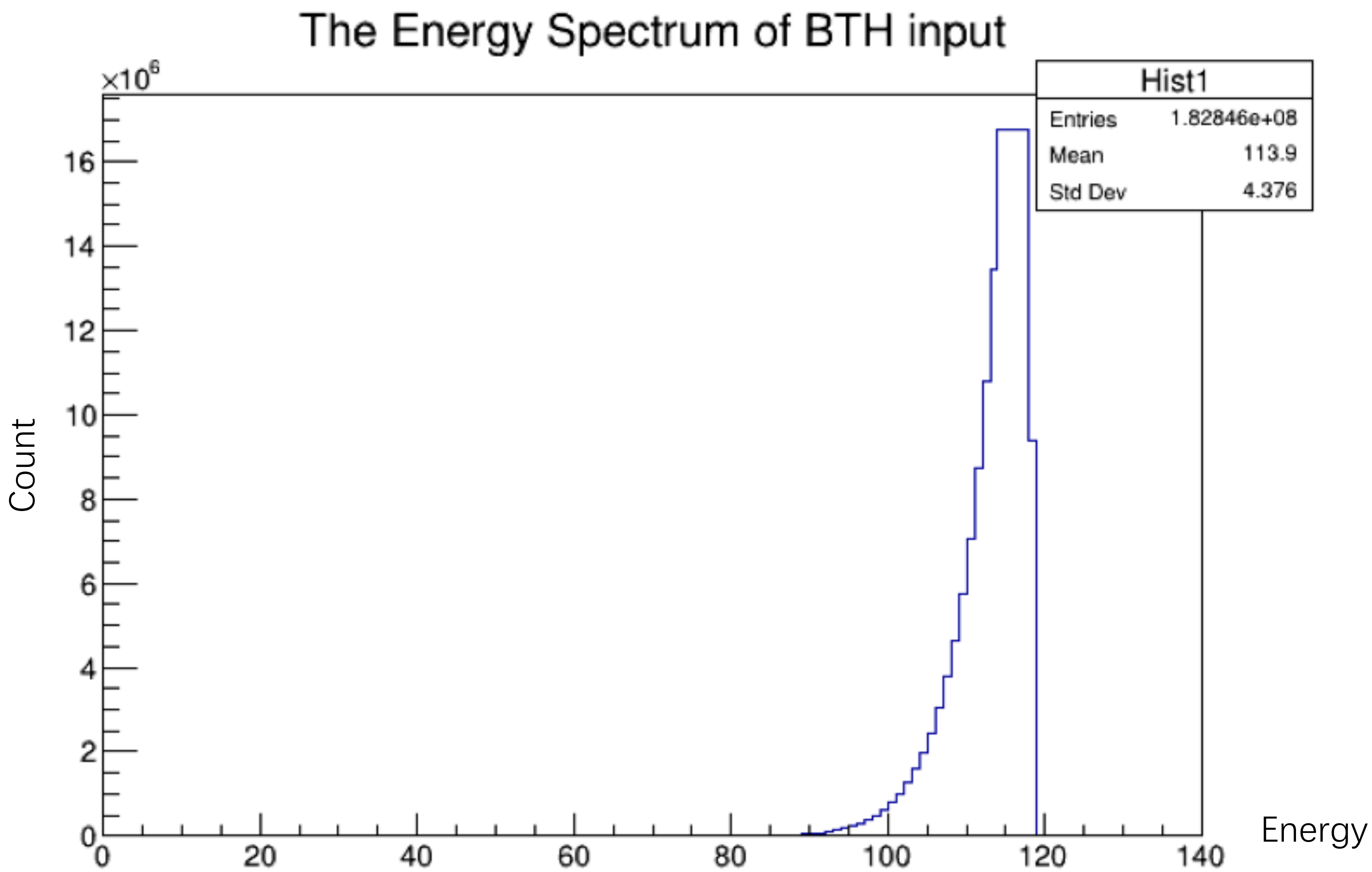


- Much 0th turn lost
- 1st turn downstream still contributes most

Beam Thermal Photon

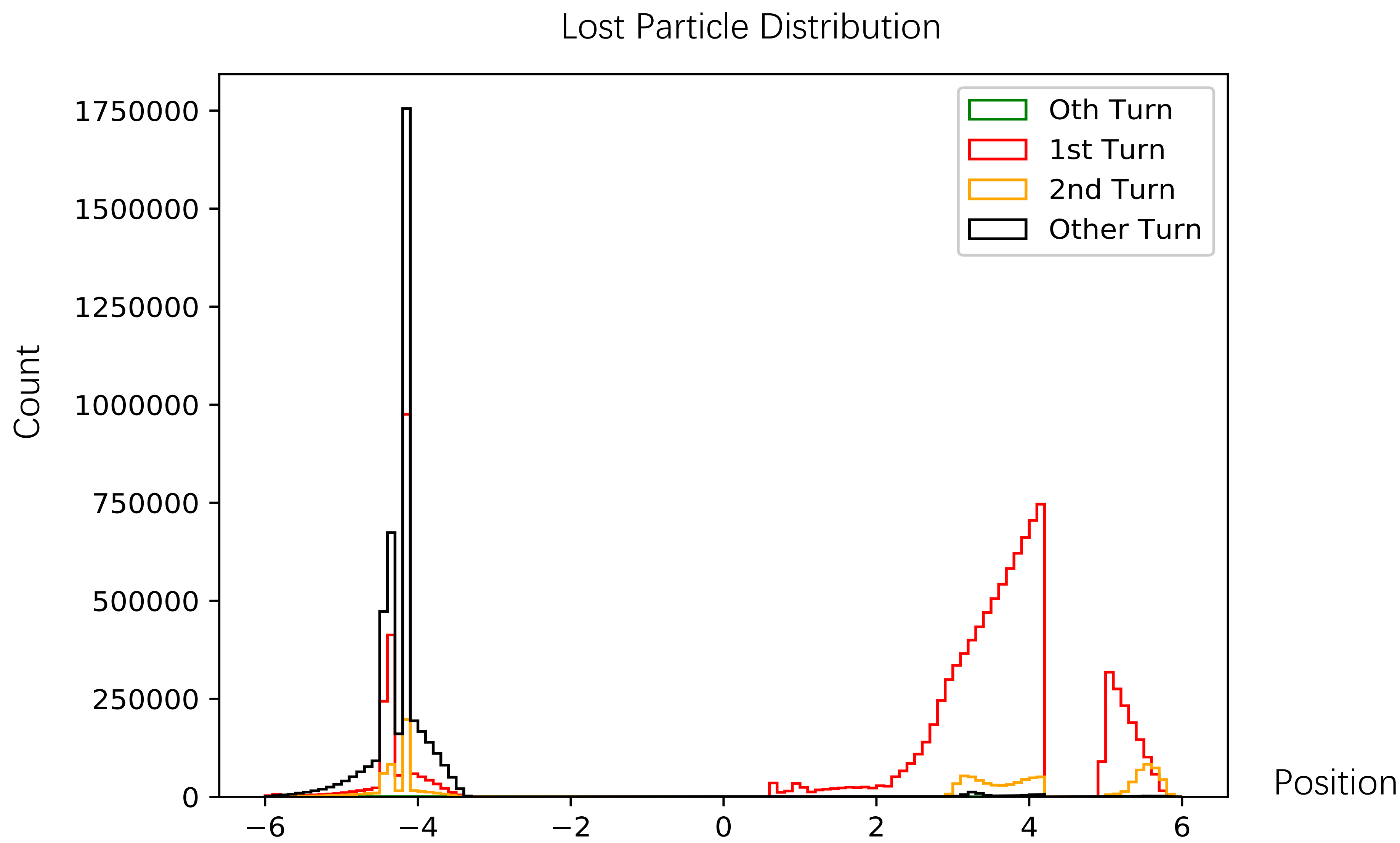
- Beam Particle interact with the photon emitted by beam pipe
  - Important on high energy machine
- The same as Beam-Gas:
- Generated by PyBTH:
  - Written by Dr. Yue
  - The scattering was generated with 200 meters to the IP
  - Tracking whole ring for many turns

Beam Thermal Photon



- The Energy Range is narrow
- We can expect No Much Lost on 1st Turn downstream

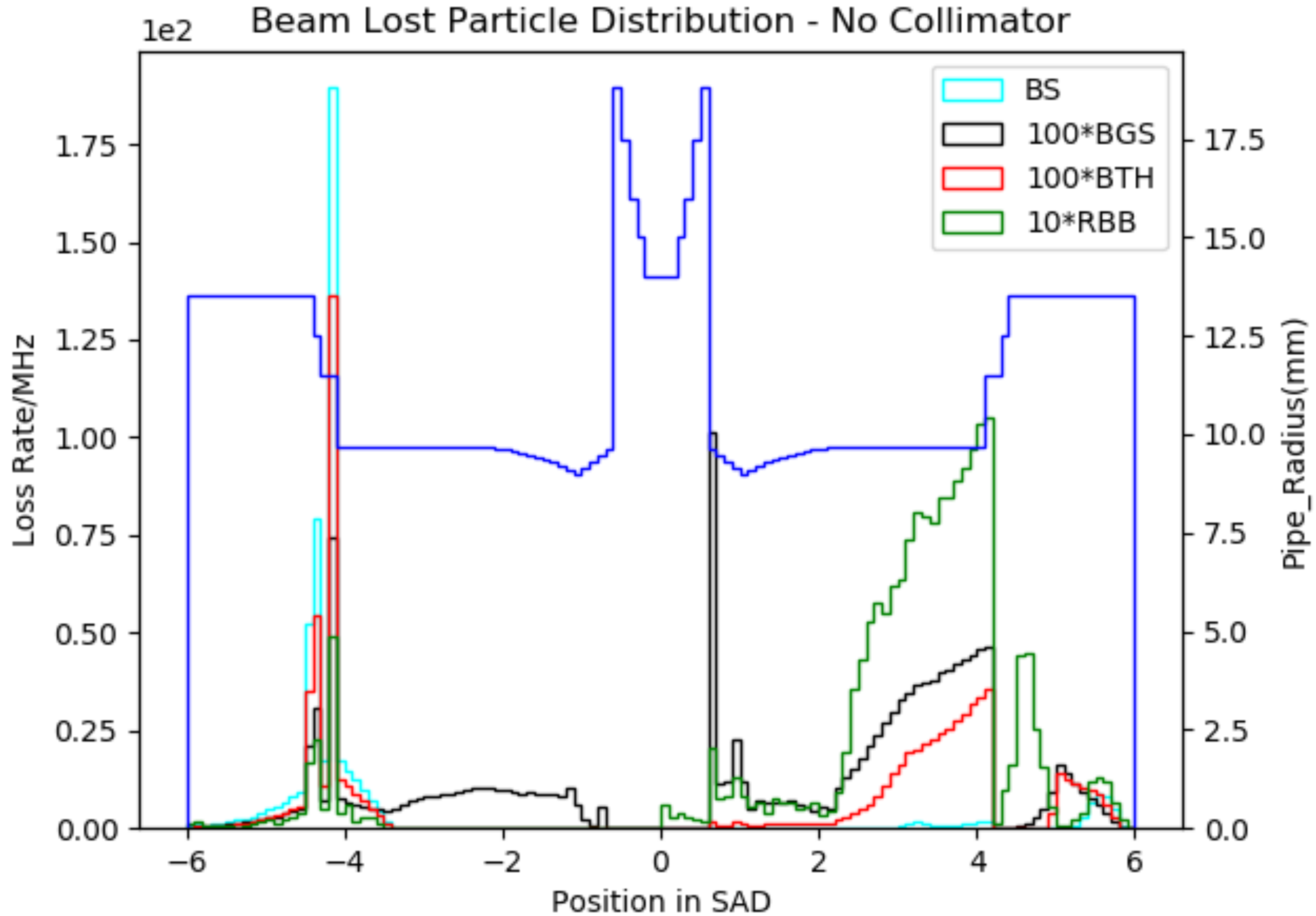
Beam Thermal Photon



- Most Contributes come from more than 2 turns

Lost Distribution without Collimators

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



Collimator

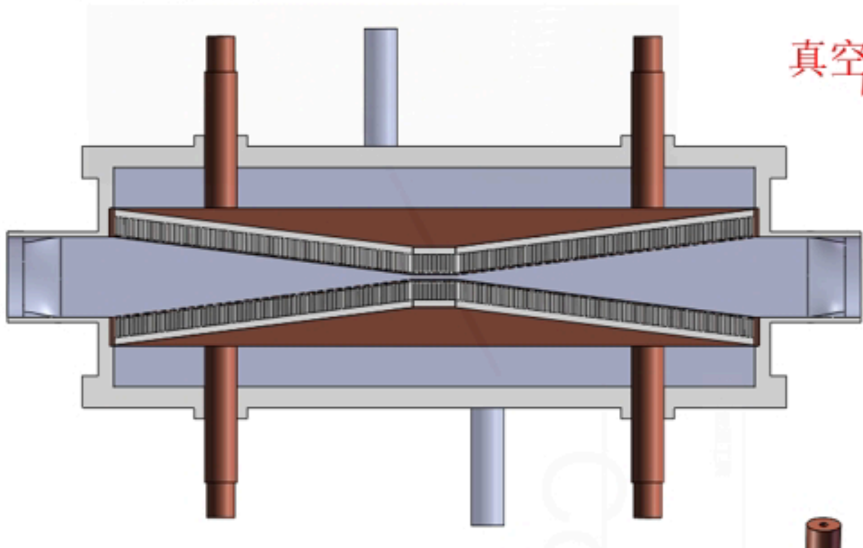
- Collimators are need.
- Now we put 2 sets of horizontal collimators, but sure to need more in future.(Trying 5th Horizontal one upstream of IR)
  - SKEKB has about 30 sets
- We only take primary into consideration.

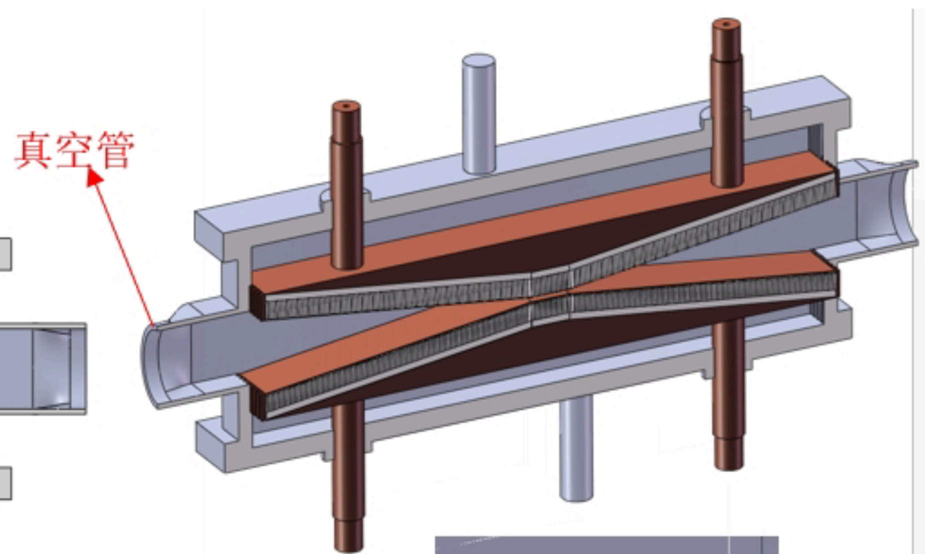
S. Bai

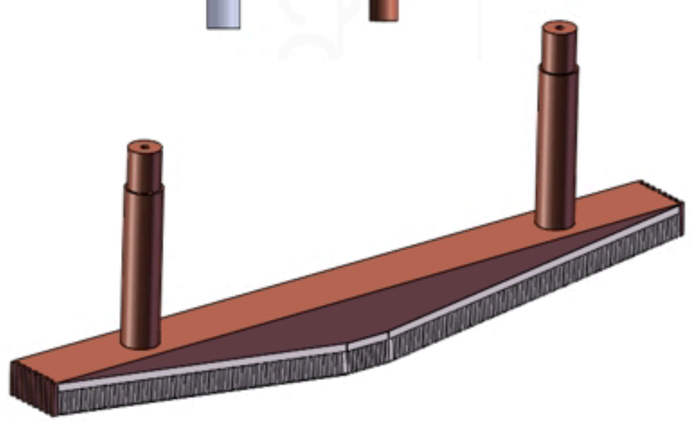
Name	Location	Distance to IP
APTX1	D1I.1897	2139.06
APTX2	D1I.1894	2207.63
APTX3	D1O.10	1832.52
APTX4	D1O.14	1901.09

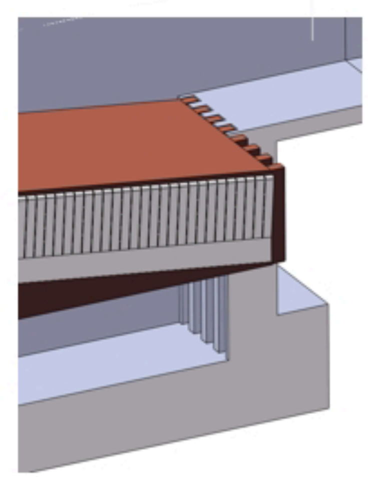
Collimator

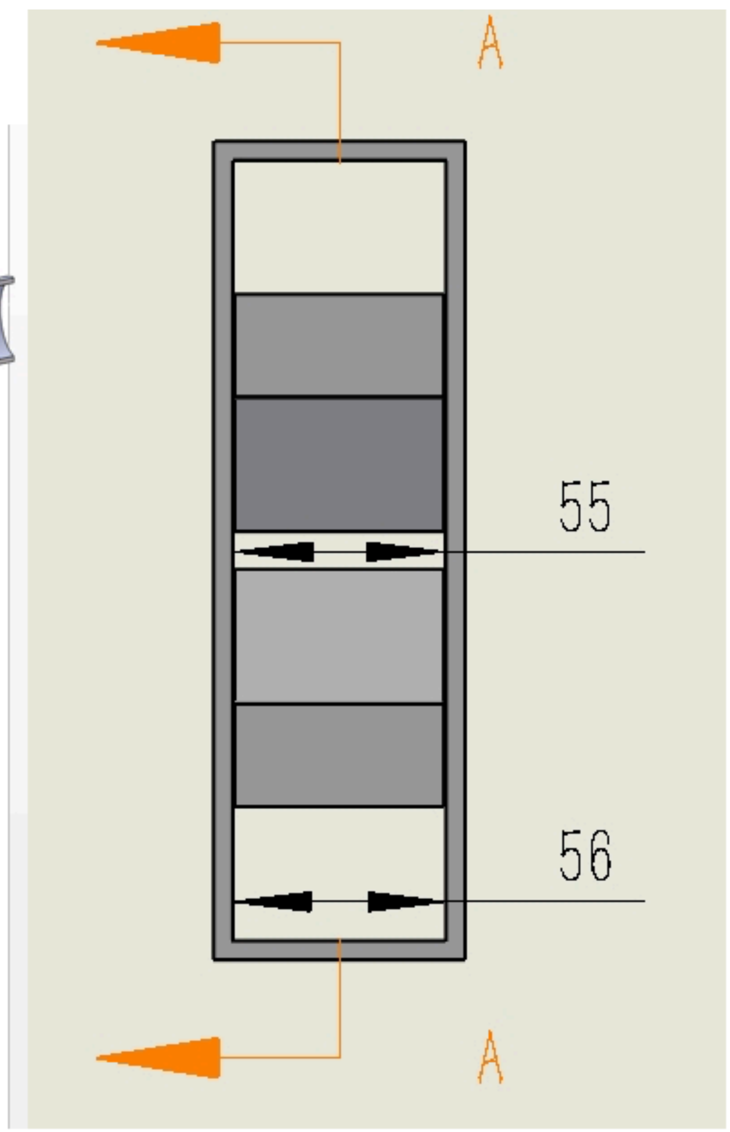
- 矩形腔方案



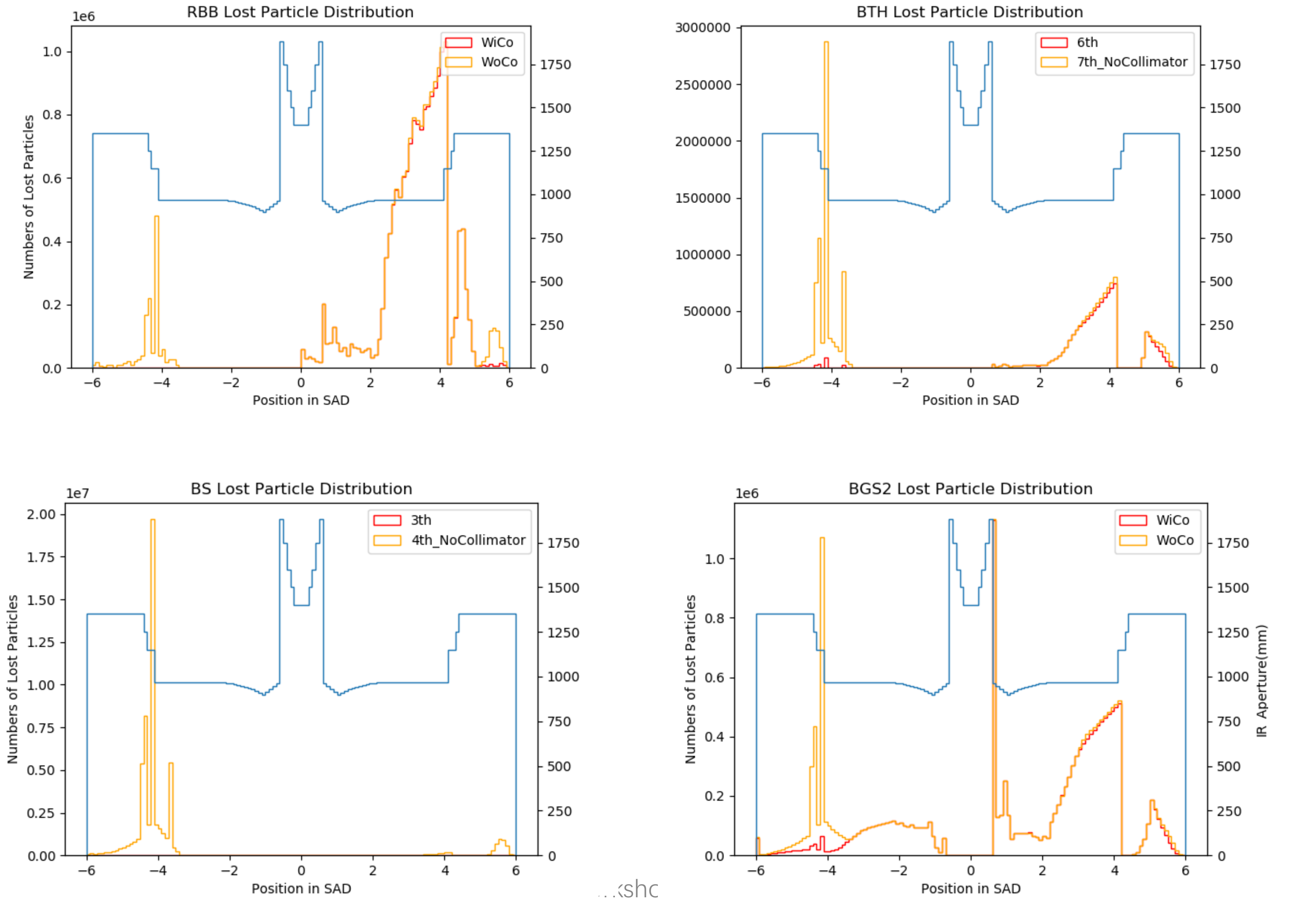




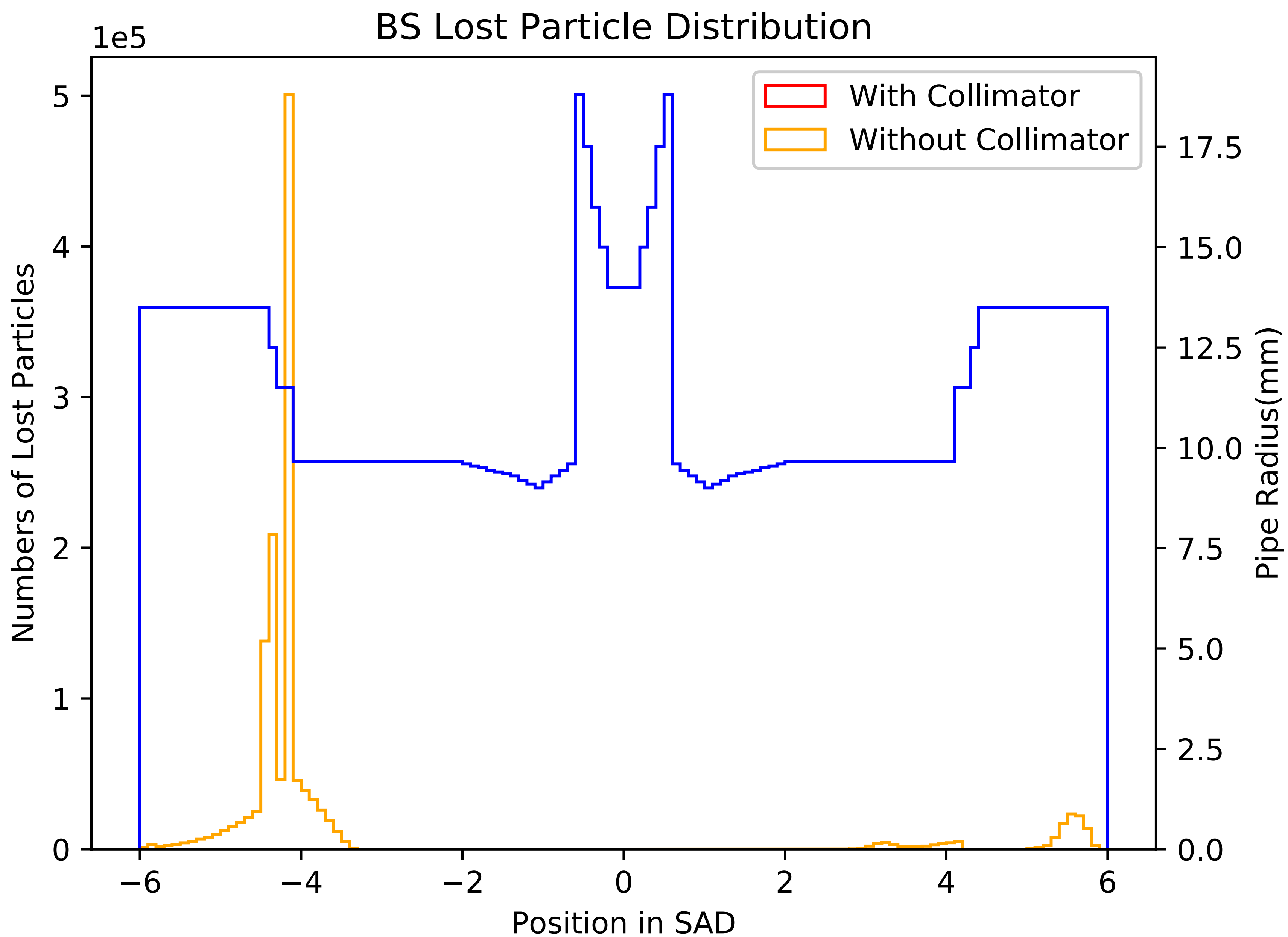




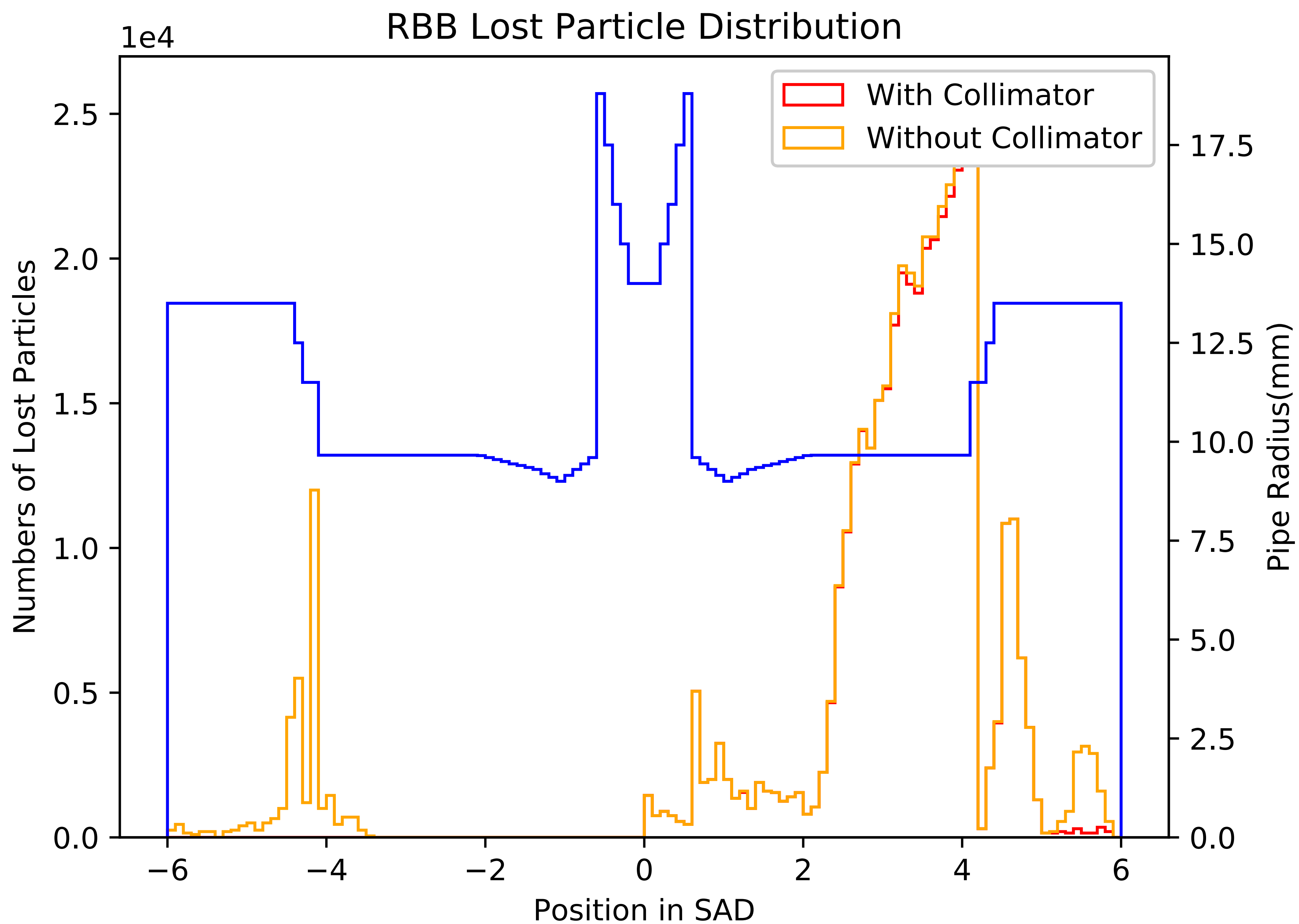
Collimator Effects



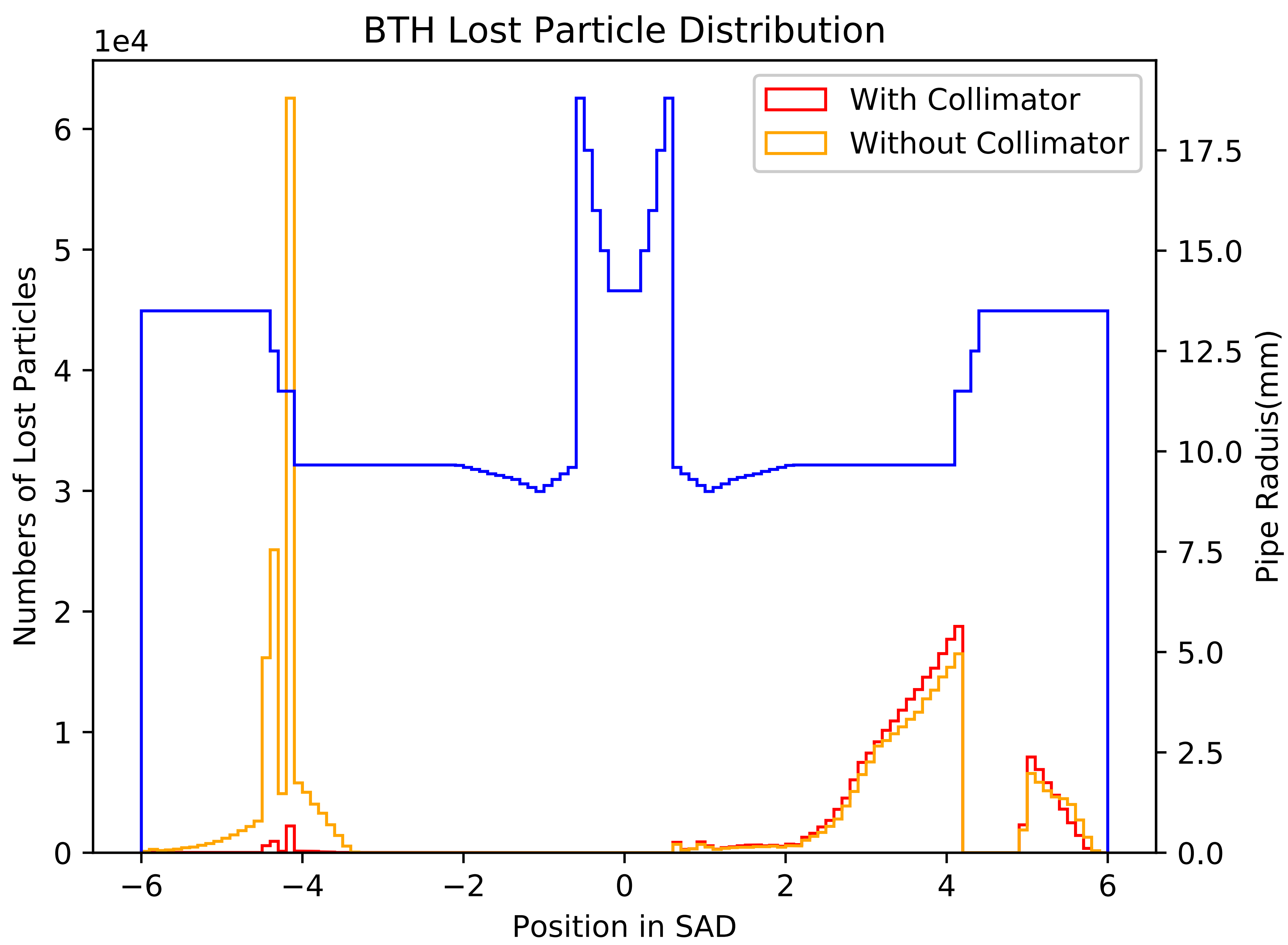
Collimator Effects - BS



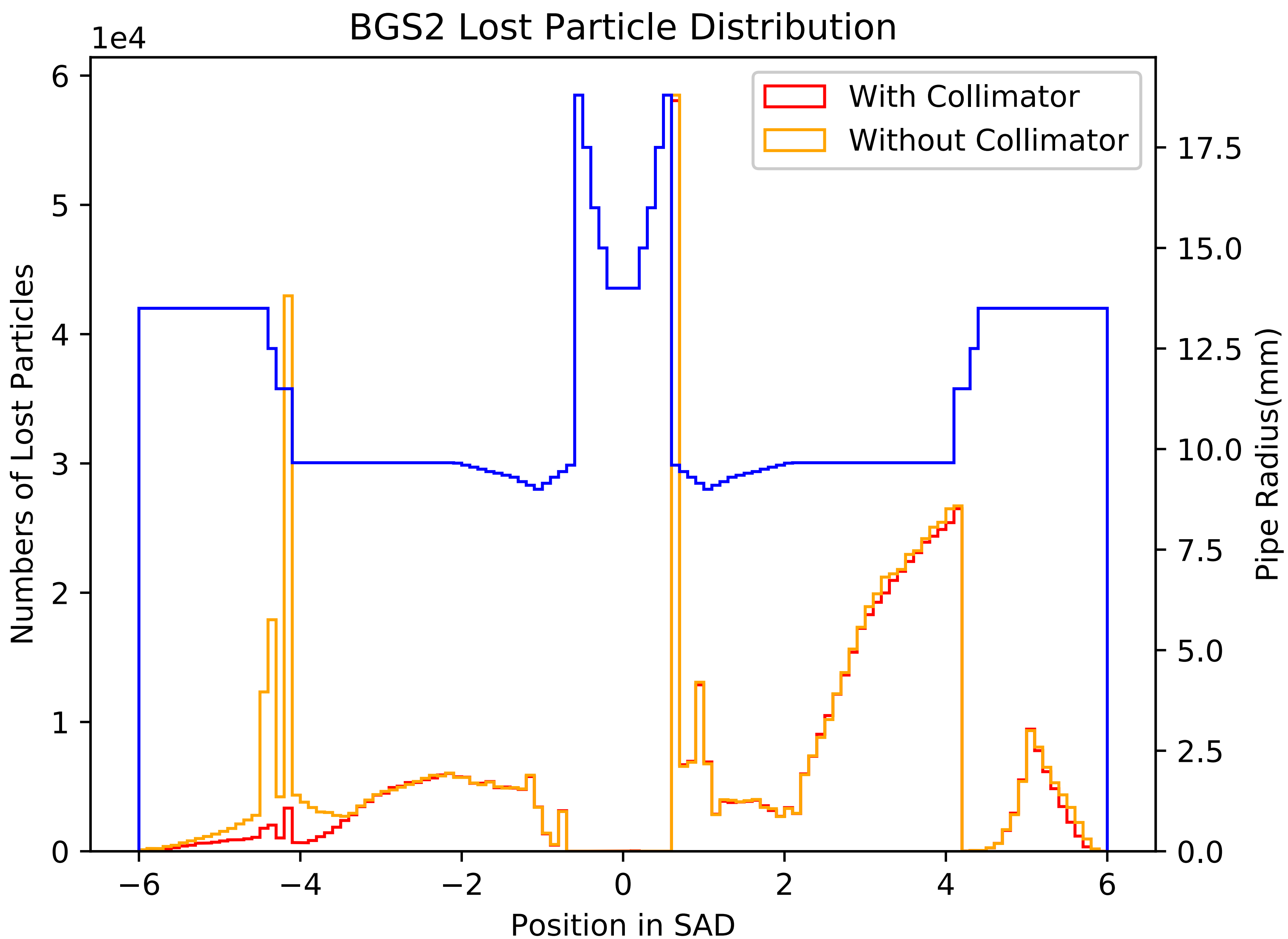
Collimator Effects - RBB



Collimator Effects - BTH



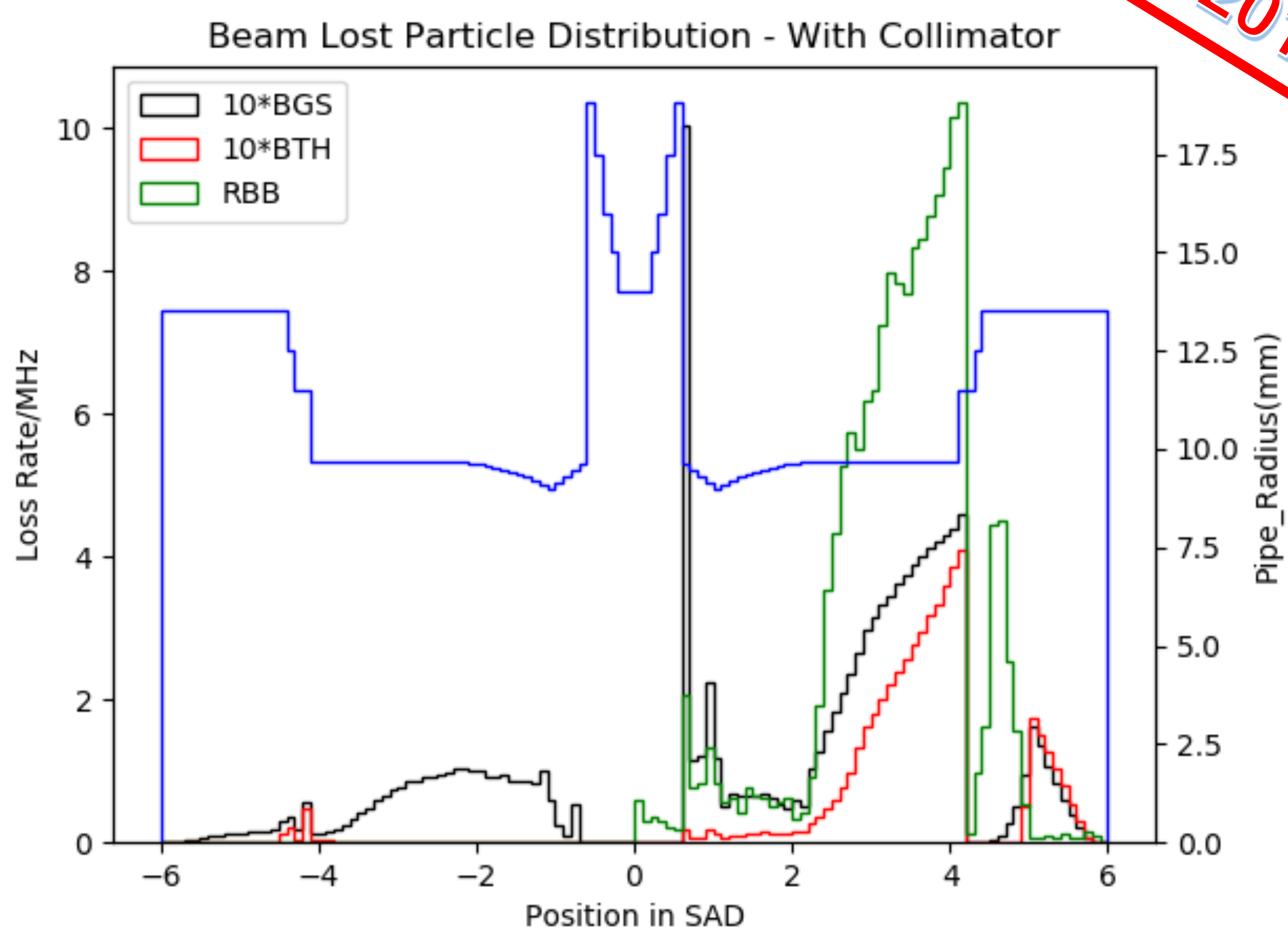
Collimator Effects – BGS2



Lost Distribution with Collimators

- Including Radiative Bhabha, Beam-Gas, Beam Thermal Photon. Almost No Beamstrahlung.

- Normalized to loss rate in MHz(one beam)



Combine Results

Preliminary 11/14/2019

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

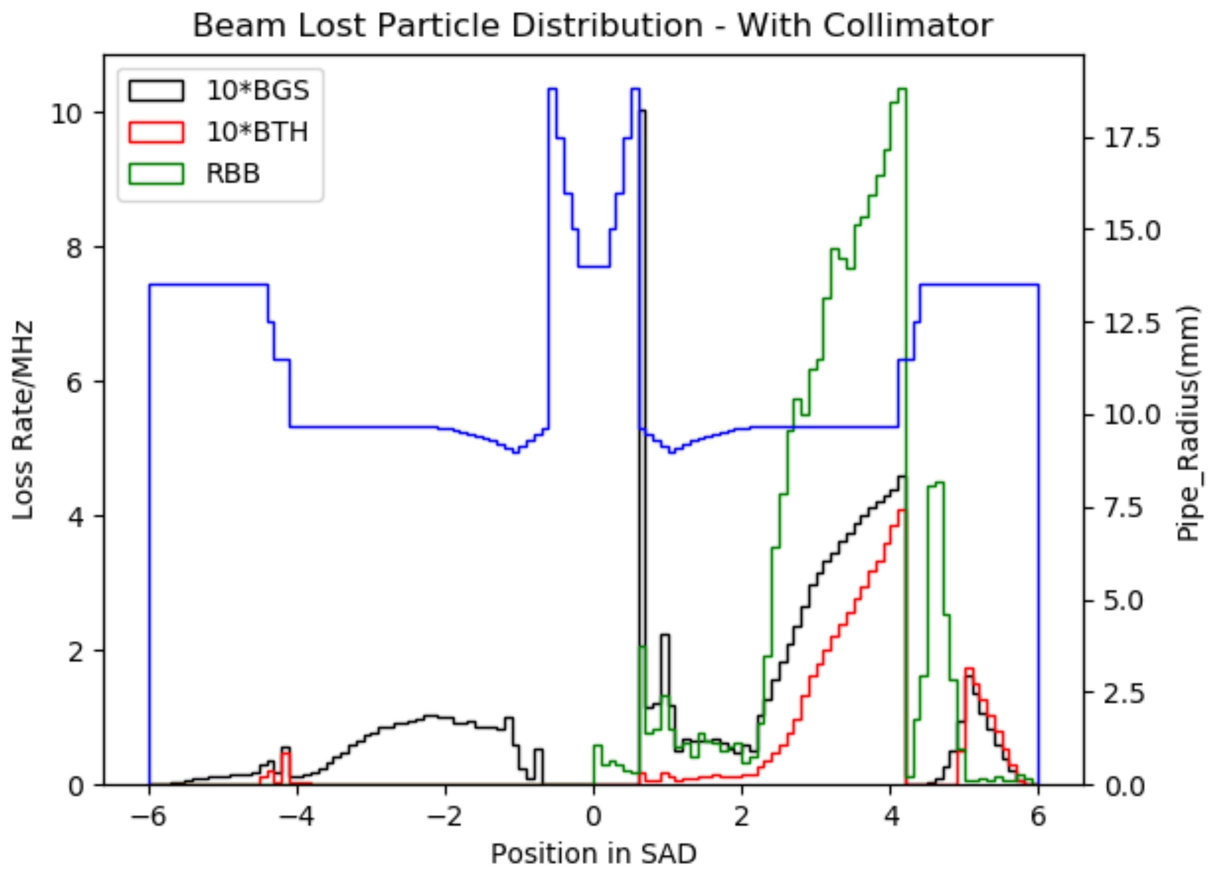
Background Type	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)	1 MeV equivalent neutron fluence ($n_{eq} \cdot cm^{-2} \cdot yr^{-1}$)
Pair production	2.26	591.14	1.11e+12
Synchrotron Radiation	0.026	15.65	
Radiative Bhabha	0.34	592.66	1.44e+12
Beam Gas	36.8372	39901.139	9.65e+13
Beam Thermal Photon	2.31	2325.49	5.48e+12
Total	41.7732	43426.079	10.453e+13

Next Step – Collimator Study

Try to add more collimator(s) close to IR

Motivation

- The Background caused by beam gas bremsstrahlung is very high even with 4 sets of horizontal collimators.
- The collimators were put about 2000 meters away from IP, however, most of the events were generator with 200m upstream of the IP, some of them would get lost immediately.
- Try to put one more set of collimator within this range, and study in detail.



Study Methods

- SAD Tracking
  - Add one more collimator in SAD Lattice.
  - Let SAD output the loss particles at the collimator.
- FLUKA Simulation
  - Build Collimator Model in FLUKA.
  - Output the electrons come out from the collimator.
  - Add a detector(0.1cm thick vacuum ring, outer radius is the radius of pipe at out of the IR, inner radius is the radius of pipe at -0.2m) at -6m.
  - For now, we mainly concern electrons/photons/neutrons.
- SAD Tracking
  - Track the electrons implemented from FLUKA
- Full Detector Simulation(Mokaa)
  - Lower primaries and secondaries(if needed)
- CAUTION: Normalization

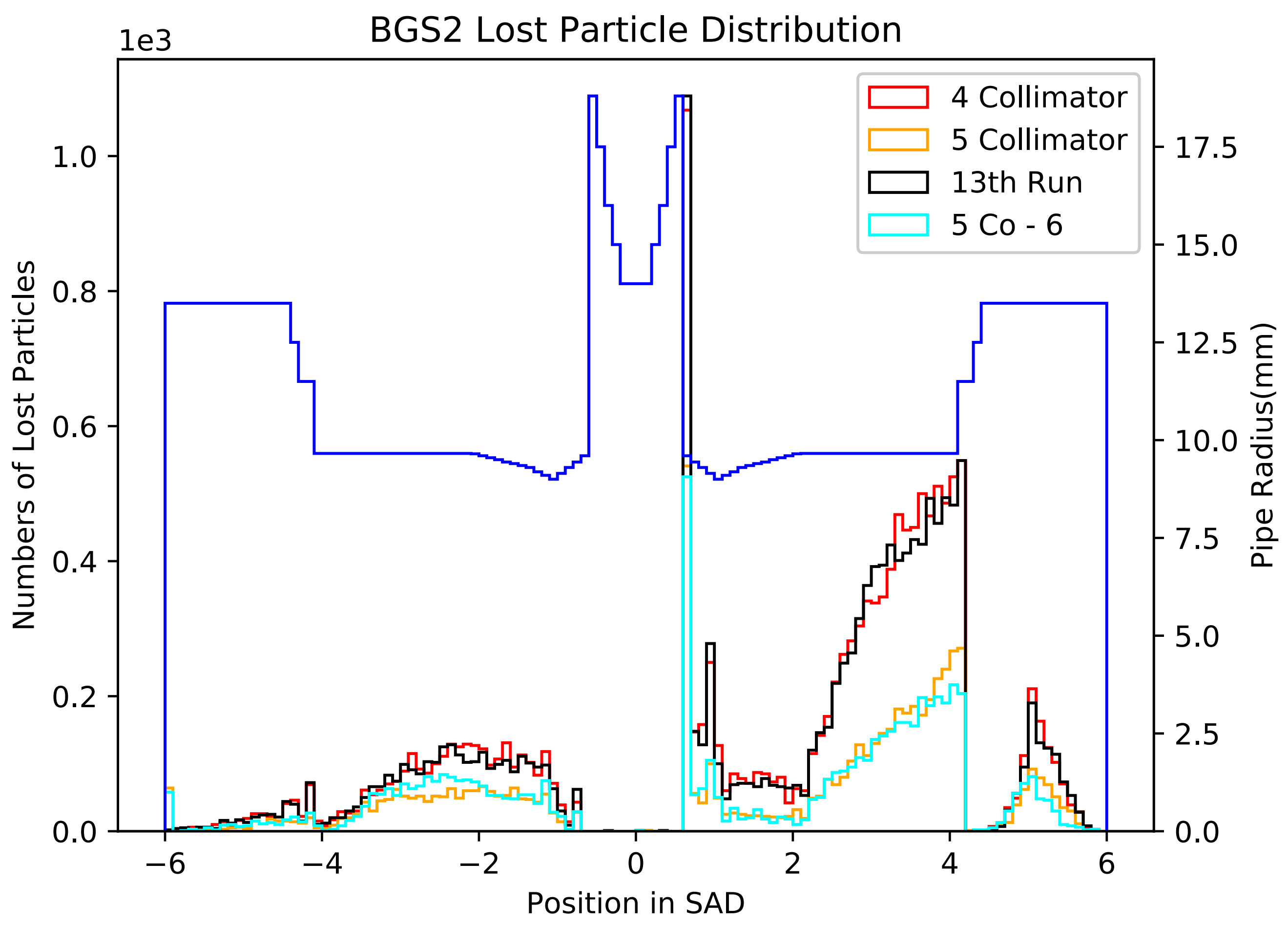
Position

- The last bending magnet located from ~-150m to -50m.
- Add a set of collimator before the last bending magnet would not help much.
- Usually people don't put collimators after the last bending magnets due to following reasons:
  - At small scale machine, the distance between collimators and IP is too short
  - Shower Concern
- For CEPC, the distance could still quite far, so we can try with shower study.
- Tried different positions, ATP2.2900(31659, ~-7m) and APT2.2000(26589,~-31m)

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.



Collimator Model

- Collimator itself:
  - Box
  - X Range: -3.75cm ~ -0.5cm (3.25cm length)
  - Y Range: -2.75cm ~ 2.75cm (5.5cm length)
  - Z Range: 0~4cm (4cm length, could be change)
  - One more in +X

- Detectors:
  - Z: 2490cm ~ 2490.1cm
  - Inner Radius: 1.4cm
  - Outer Radius: 3.75cm

Initial Results – Electrons

- One job, 94375 events generated.
- 9162 lost at -30.92m, most of them were 0th turn lost(lost before the reach the IP).
- Almost all the lost within the IR would be located at -5.95m with energy lower than 1GeV
- ~ 420 secondary electrons lost per bunch crossing
- Due to long distance and low energy, it might be safe to detectors
- We will perform full detector simulation later

Initial Results – Photons

- Record the photons at -6m.
- Since all the secondary photons came out from collimator located at -31m, if they can survive at -6m, they must be very forward photons.
  - All the cosZ of the survived photons > 0.9999
  - If they were recorded by the detector, they would hit the magnets
  - If they were not, they might already lose, or they would just pass the detector with beam.
- Tried with different collimator models, suggested by Michael K. Sullivan

Collimators	Photons per BX	Average Energy
4cm Cu	261	1.62GeV
10cm Cu	121	0.42GeV
10cm Cu + 4cm Pb	18	93MeV
10cm Cu + 4cm W	5.17	106MeV

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

Summary & Outlook

- Background Checklist

Things	Status
Analyze the Backgrounds	Done
Find Generators for Backgrounds	Done
Check the generators	Partial Done
Generate Backgrounds	Done with current design
Build the model with current design	Need to Update
Track the beam induced backgrounds	Done with current design
Verify Tracking Codes	To Do
Set Collimators	Partial Done
Collimator Study	Just Started
Detector Simulation	Done with current design
Verify Simulation	To Do
Safety Factor Check	To Do

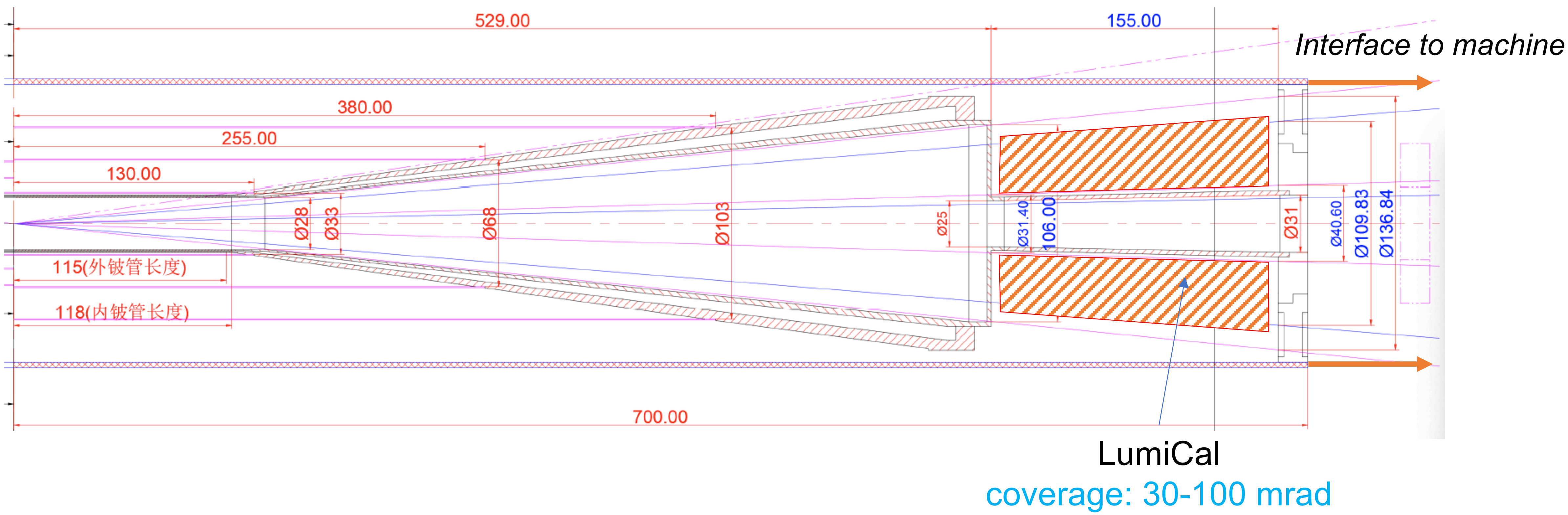
Summary & Outlook

- Till Now, we:
  - Analysis all the background sources, and could generate each of them
  - Preliminarily estimate the background levels with CDR Design

- Next, we should:
- Validate the simulation codes with background data from other storage ring&colliders:
  - BEPCII, LEP(II), SKEKB, etc.
- Push work towards TDR:
  - Update with new designs of accelerator & detector
  - Study each source carefully, in real situation.

Thank You

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)