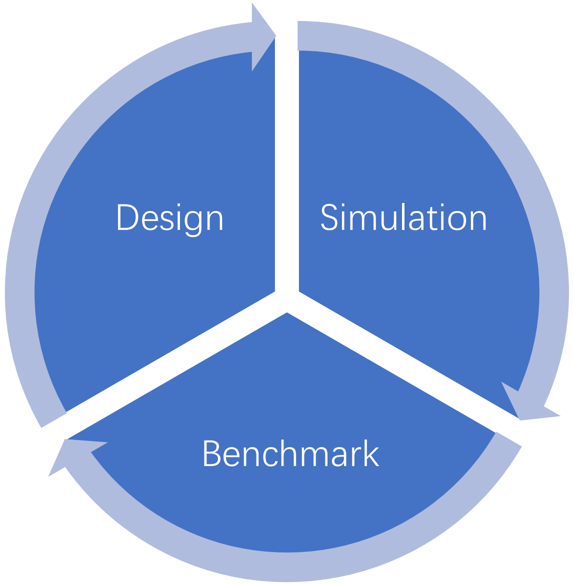
Progress on CEPC MDI Background Study

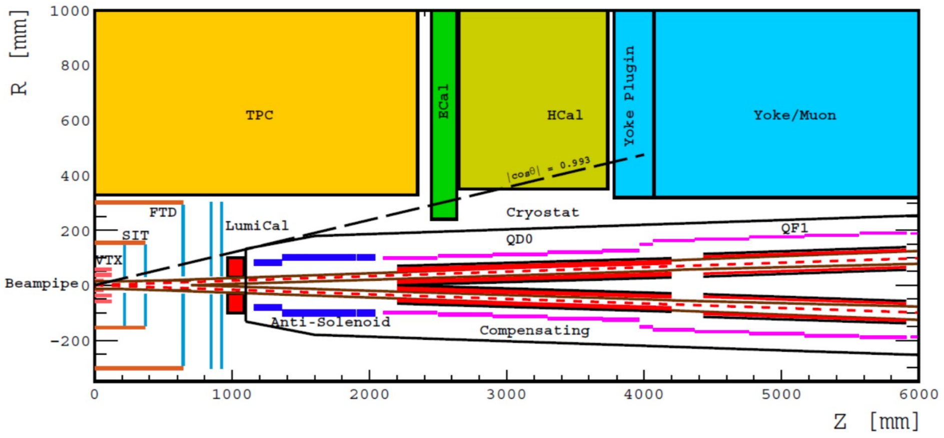
Haoyu SHI

On Behalf of CEPC MDI Working Group

CEPC DAY, 2021.3.25

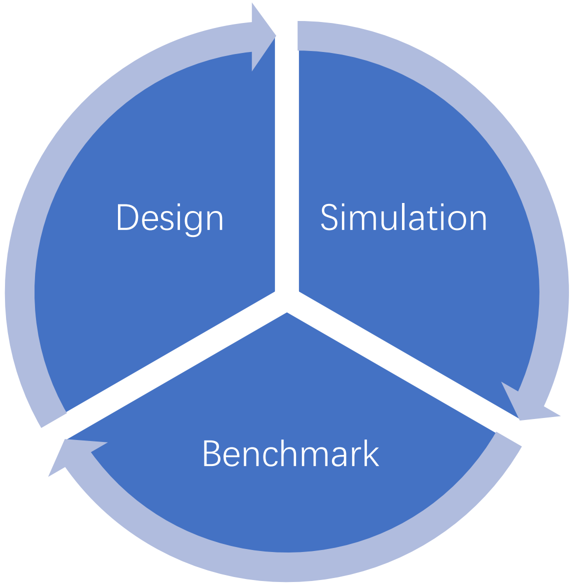
Radiation Backgrounds



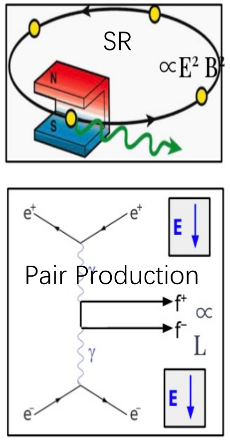


	Higgs	*W*	*Z (3T)*	*Z (2T)*
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5×2			
Piwinski angle	2.58	7.0	23.8	
Number of particles/bunch N_e (10^{10})	15.0	12.0	8.0	
Bunch number (bunch 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**

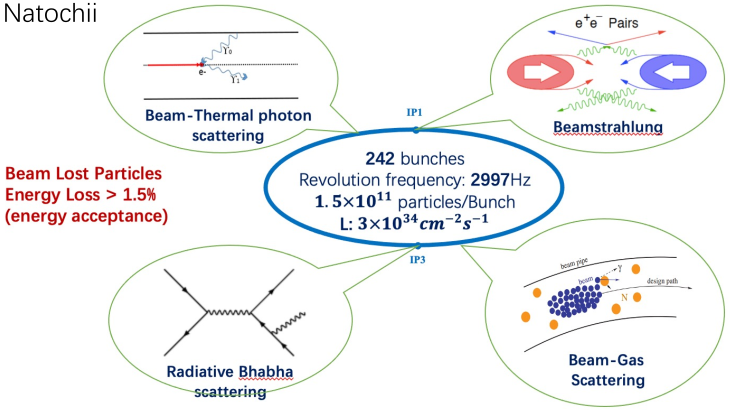
Radiation Backgrounds



A. Natochii

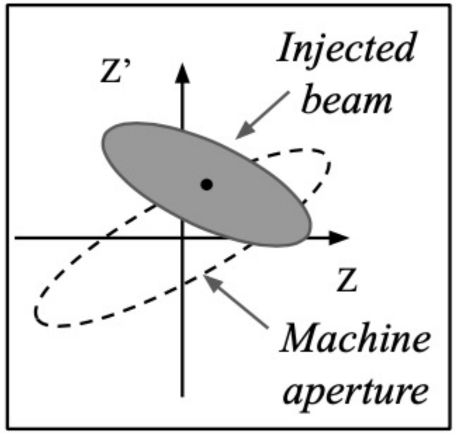


Photon BG



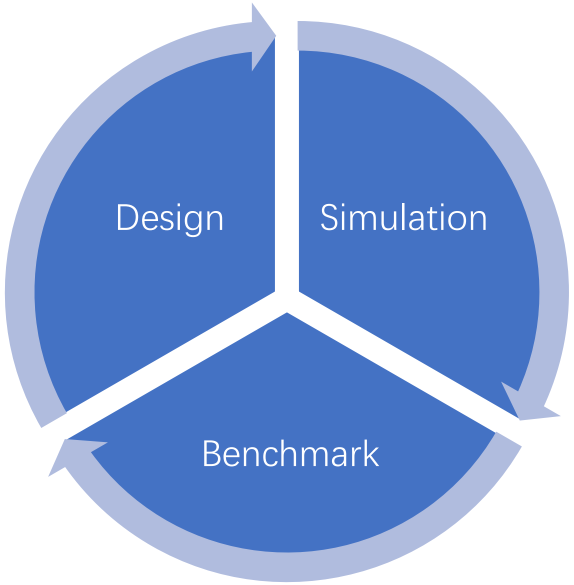
Beam Loss BG

A. Natochii

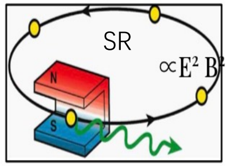


Injection BG

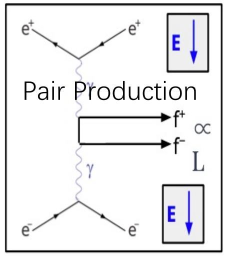
Radiation Backgrounds



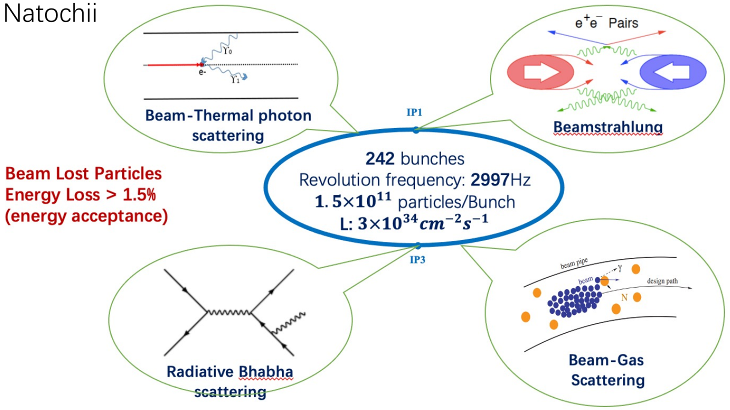
- Photon BG and Beam Loss BG were simulated using different tools. Injection BG is ignored for now.
  - Cross-check and benchmark needed.
- Other BGs are planned to study.



A. Natochii

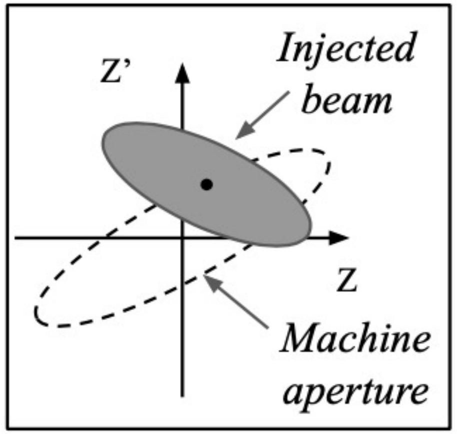


Photon BG



Beam Loss BG

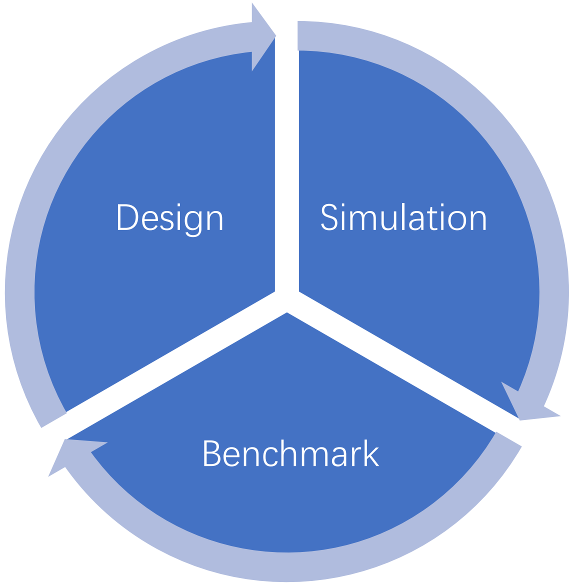
A. Natochii



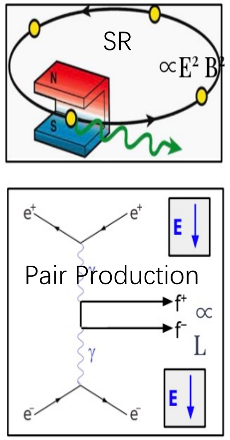
Injection BG

<table>
<tr><th>Background</th><th>Generation</th><th>Tracking</th><th>Detector Simu.</th></tr>
<tr><td>Synchrotron Radiation</td><td>BDSim</td><td>BDSim/Geant4</td><td rowspan="5">Mokka</td></tr>
<tr><td>Beamstrahlung/Pair Production</td><td>Guinea-Pig++</td><td rowspan="4">SAD</td></tr>
<tr><td>Beam-Thermal Photon</td><td>PyBTH</td></tr>
<tr><td>Beam-Gas Bremsstrahlung</td><td>PyBGB</td></tr>
<tr><td>Radiative Bhabha</td><td>Bbbrem/PyRBB</td></tr>
</table>

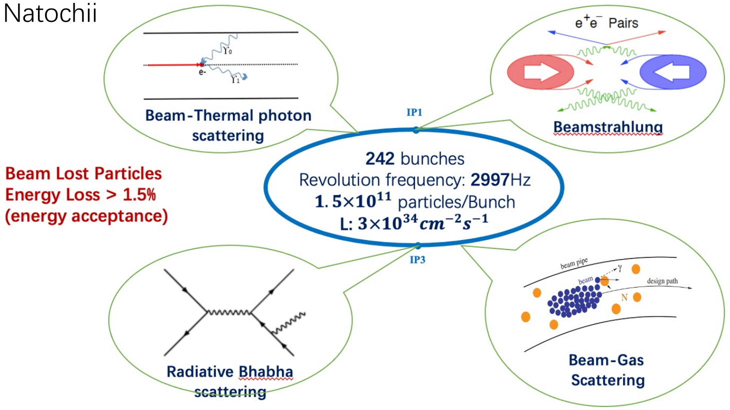
Radiation Backgrounds



A. Natochii

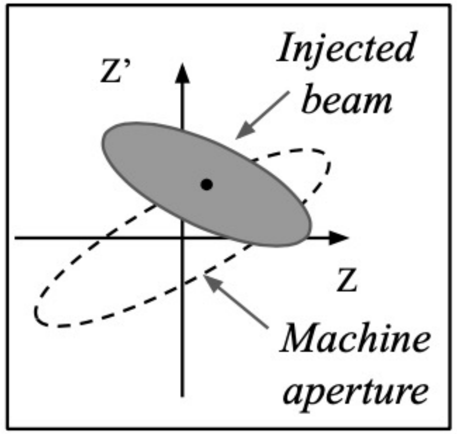


Photon BG



Beam Loss BG

A. Natochii



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.

<table>
<tr><th>Background</th><th>Generation</th><th>Tracking</th><th>Detector Simu.</th></tr>
<tr><td>Synchrotron Radiation</td><td>BDSim</td><td>BDSim/Geant4</td><td rowspan="5">Mokka</td></tr>
<tr><td>Beamstrahlung/Pair Production</td><td>Guinea-Pig++</td><td rowspan="4">SAD</td></tr>
<tr><td>Beam-Thermal Photon</td><td>PyBTH</td></tr>
<tr><td>Beam-Gas Bremsstrahlung</td><td>PyBGB</td></tr>
<tr><td>Radiative Bhabha</td><td>Bbbrem/PyRBB</td></tr>
</table>

Starting with Synchrotron Radiation

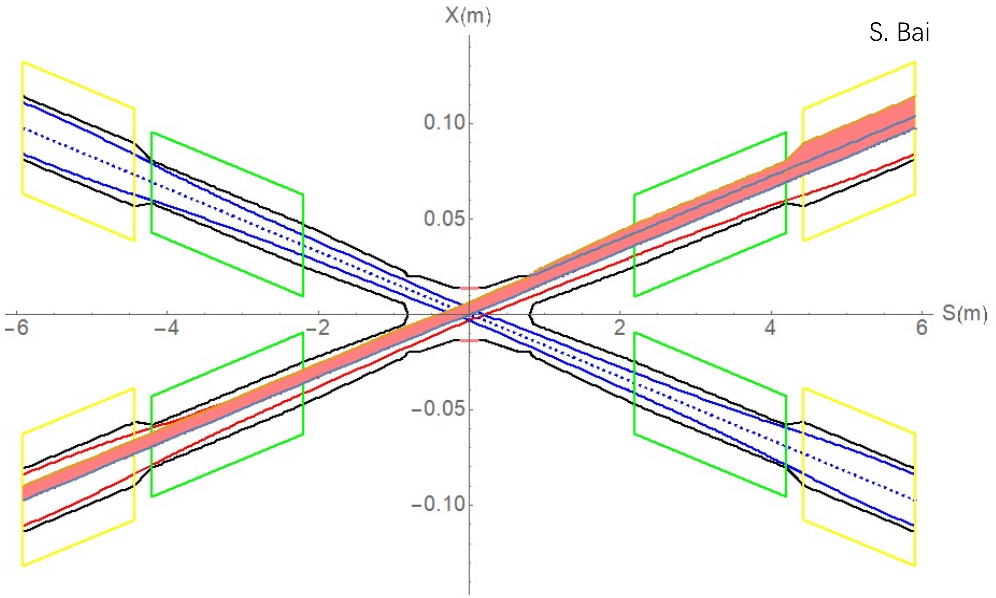
- Original central beam pipe design need to be improved.
- Synchrotron radiation should be dealt with high priority at circular machines when designing the interaction region due to high hitting number/power/detector impact

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)

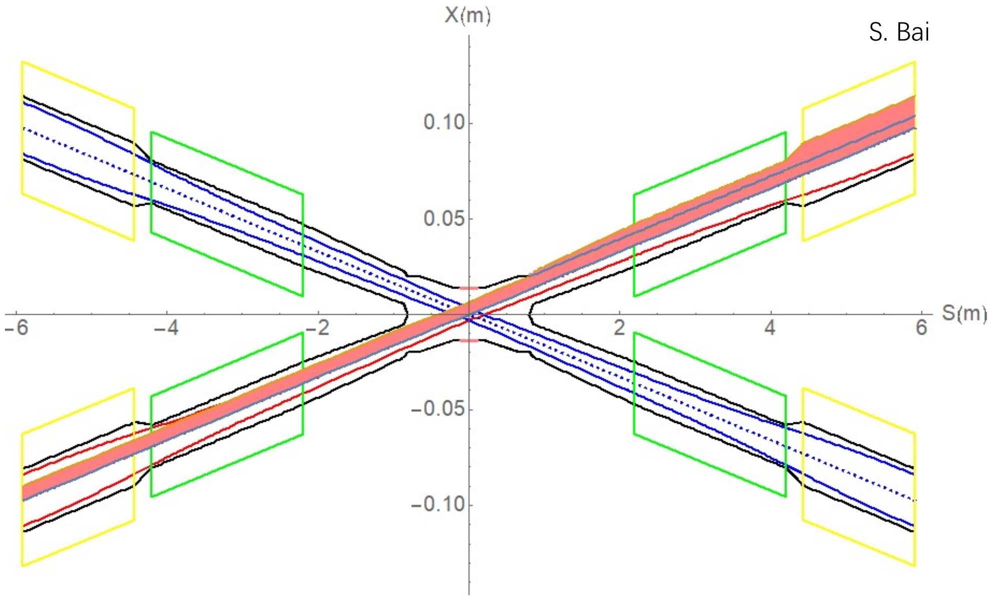


Starting with Synchrotron Radiation

- 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)

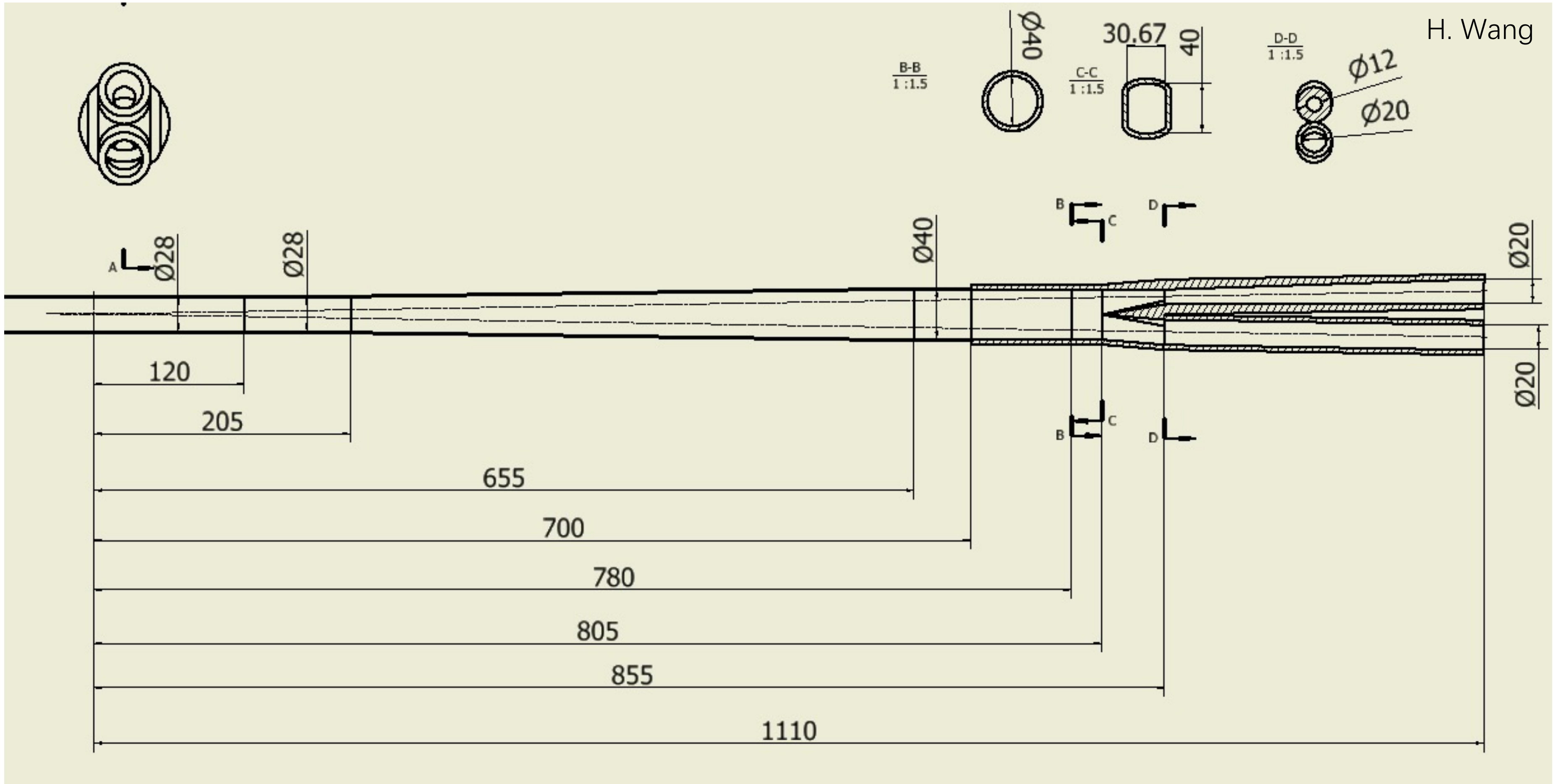


S. Bai

	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

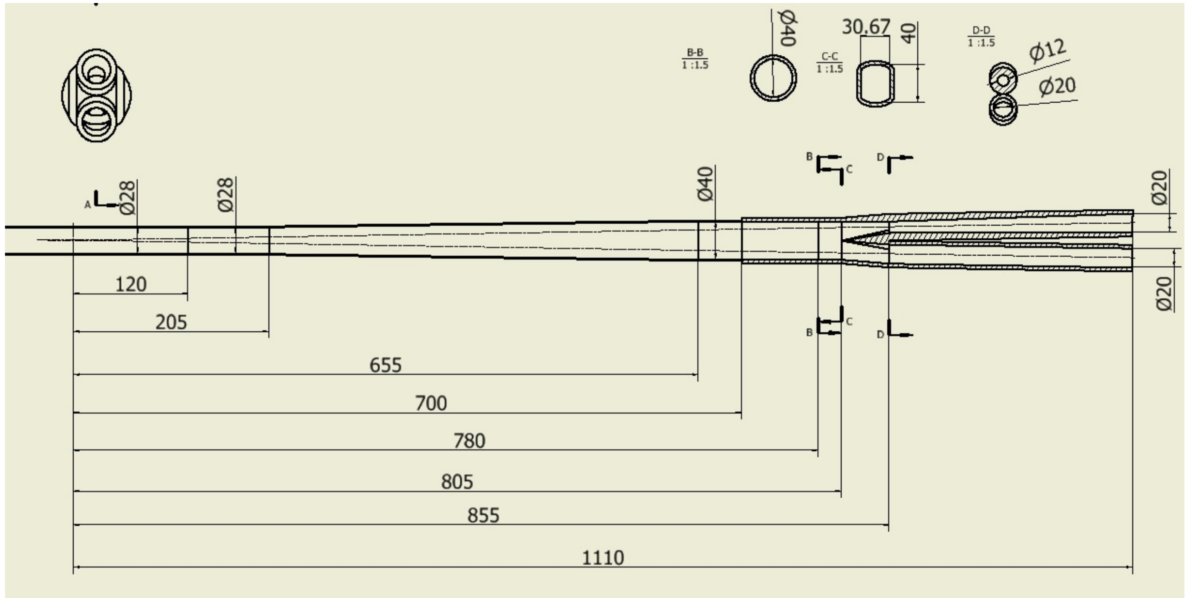
Asymmetry design

1. Error Cases
2. Scattered Photons



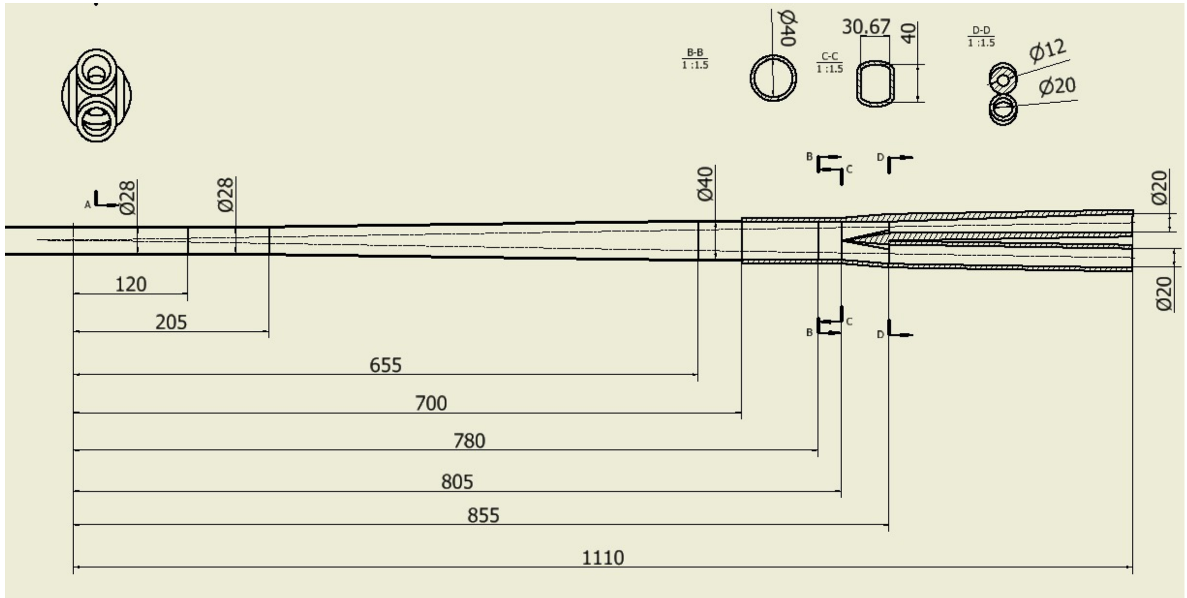
Asymmetry design

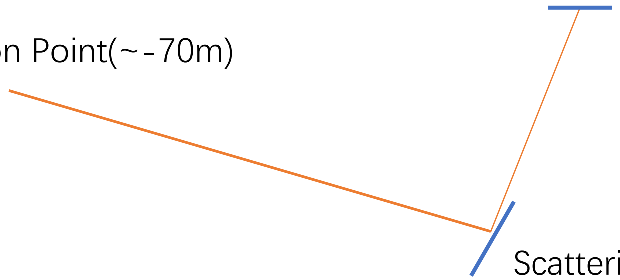
- ~40000 photons would hit Be beampipe per bunch crossing
  - Consistent with CDR results



Asymmetry design

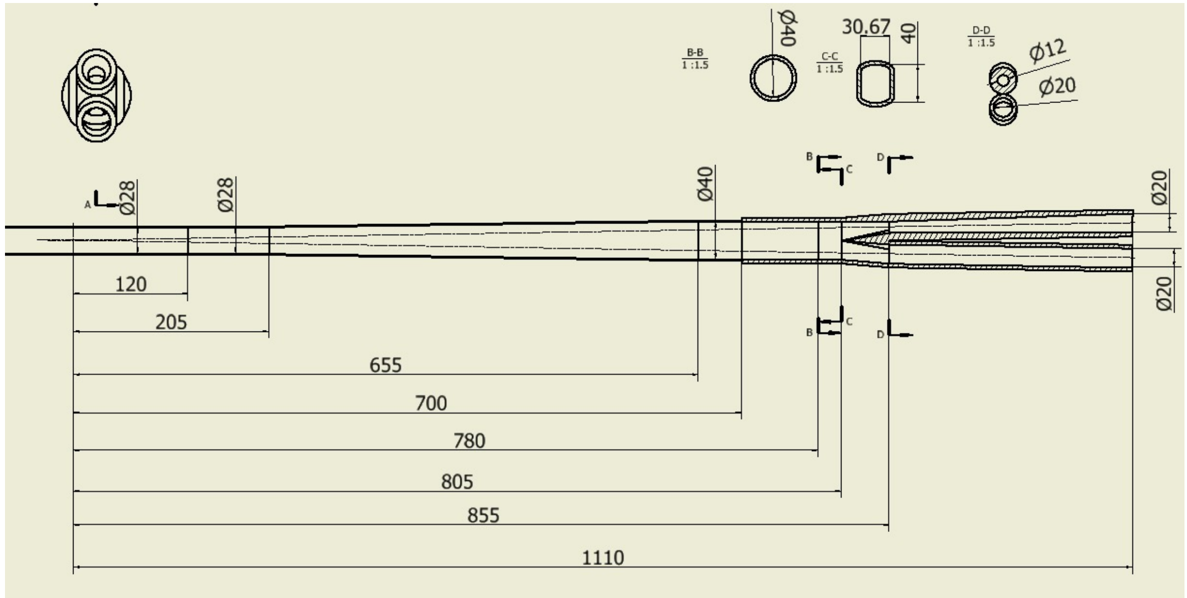
- ~ 40000 photons would hit Be beampipe per bunch crossing
  - Consistent with CDR results
- Most photons hitting Be pipe were generated at ~-70m.
  - Photons should hit the slope at ~-1.11m to -0.855m, and then scattered to Be pipe.

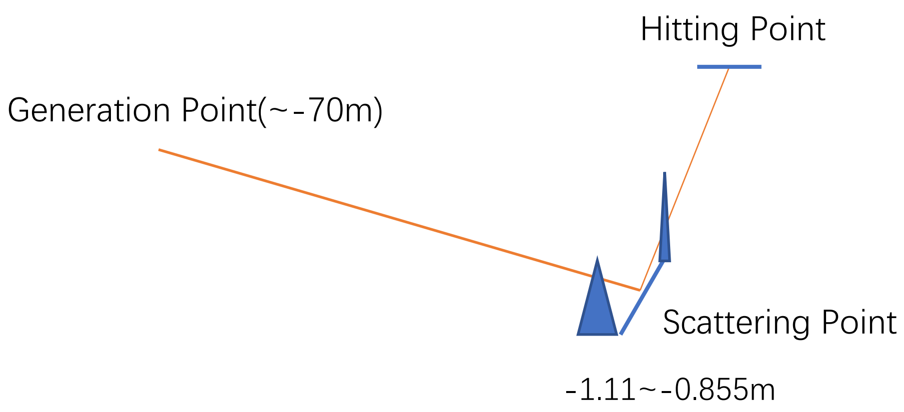




Asymmetry design

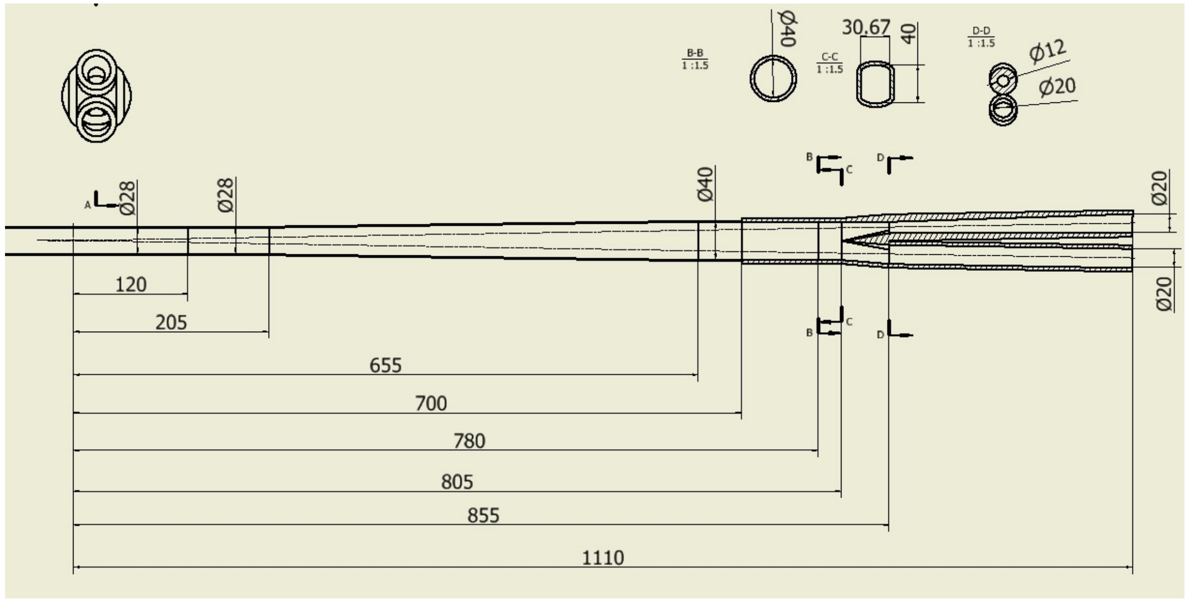
- ~ 40000 photons would hit Be beampipe per bunch crossing
  - Consistent with CDR results
- Most photons hitting Be pipe were generated at ~-70m.
  - Photons should hit the slope at ~-1.11m to -0.855m, and then scattered to Be pipe.
- Masks are needed.
  - We have tried different positions, but it seems hard to decrease the Be hitting numbers.(~32500/BX)

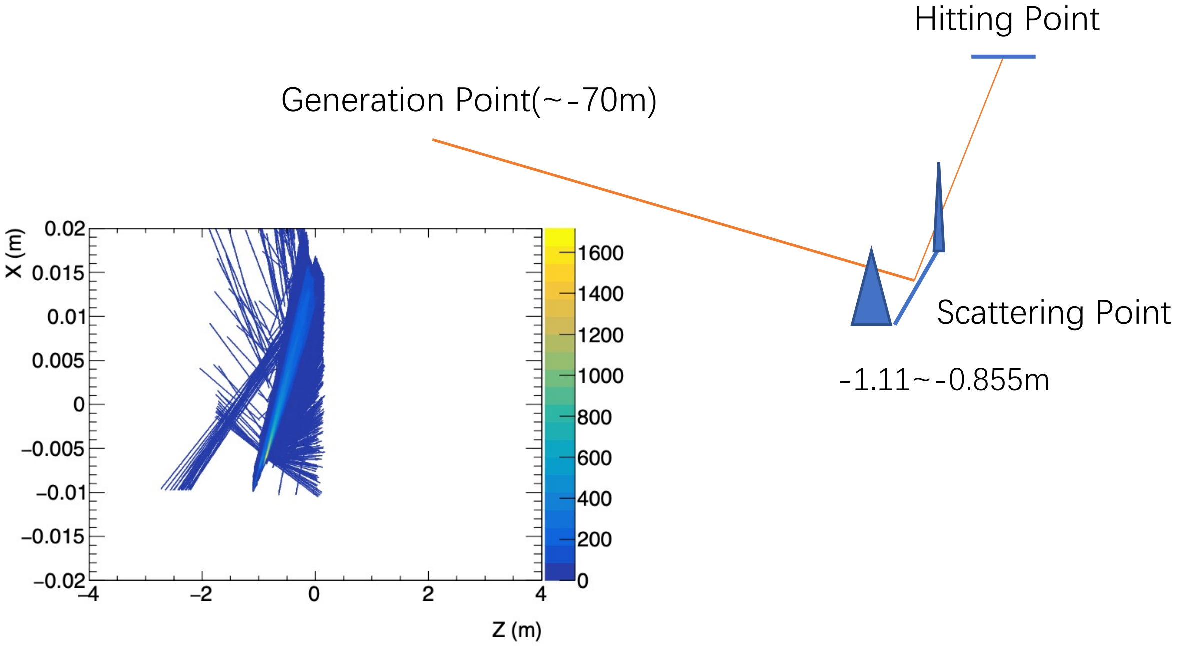




Asymmetry design

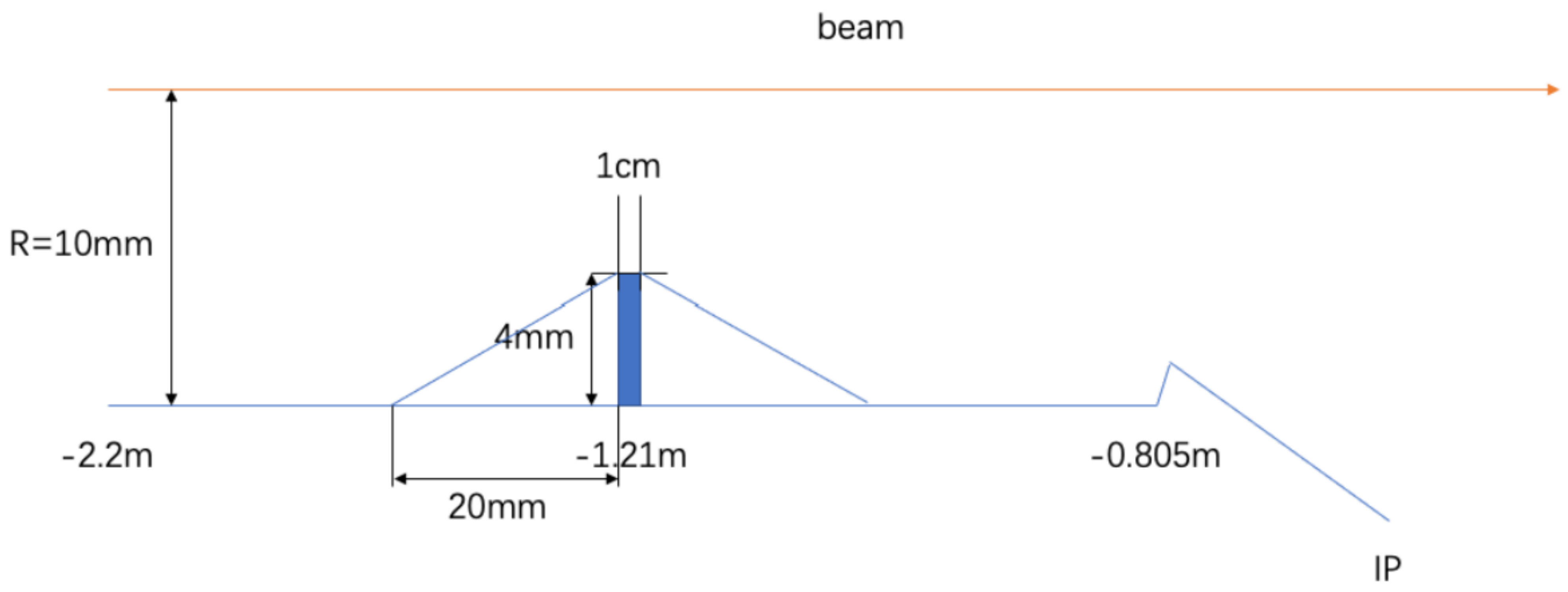
- ~ 40000 photons would hit Be beampipe per bunch crossing
  - Consistent with CDR results
- Most photons hitting Be pipe were generated at ~-70m.
  - Photons should hit the slope at ~-1.11m to -0.855m, and then scattered to Be pipe.
- Masks are needed.
  - We have tried different positions, but it seems hard to decrease the Be hitting numbers.(~32500/BX)
  - We need to know the source of the photon.





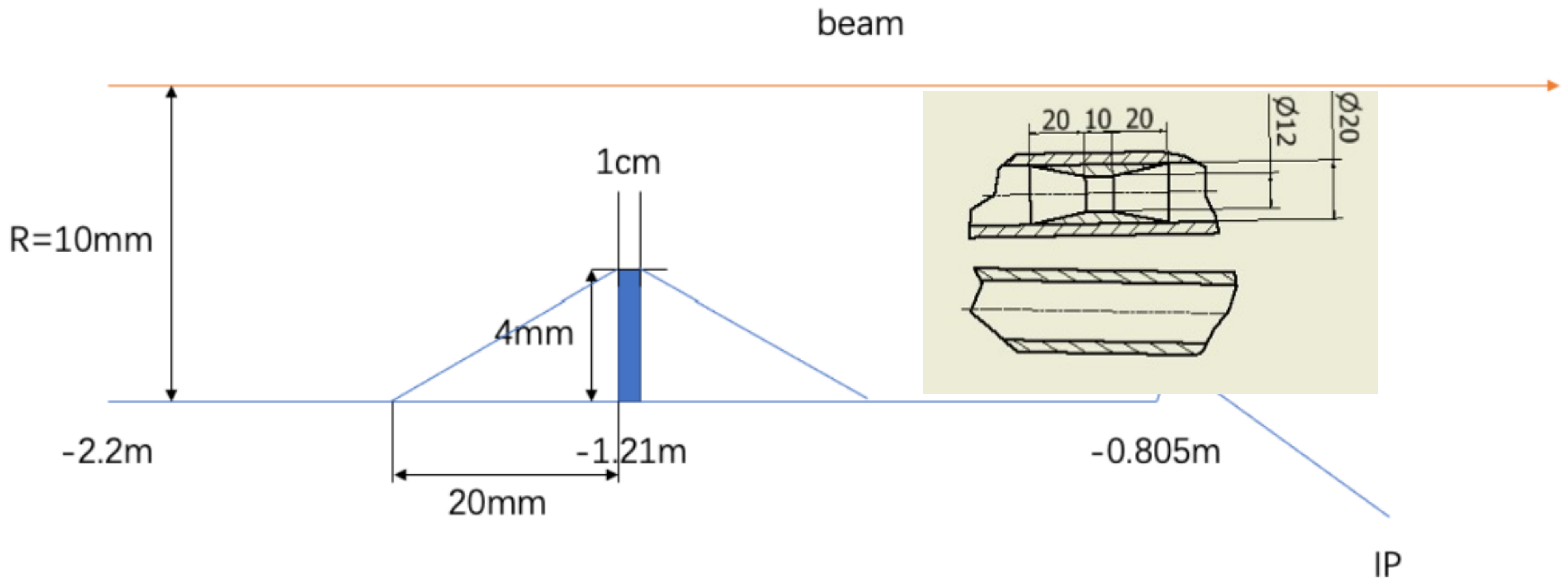
Mitigation – SR Mask

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

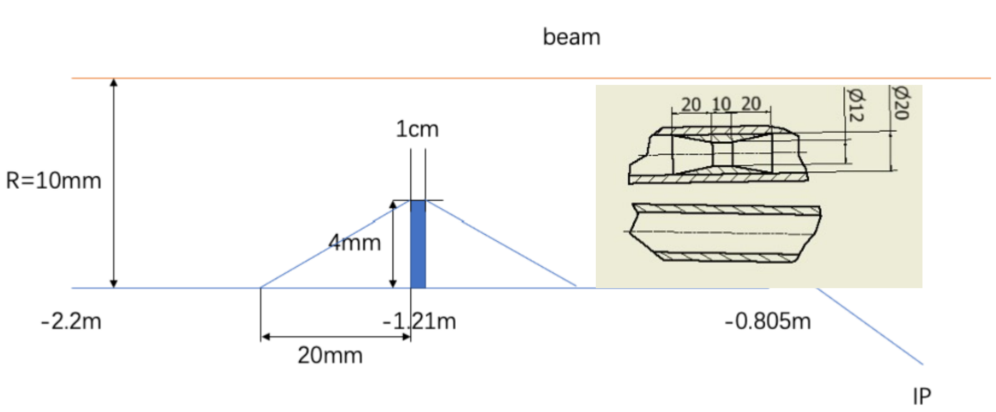


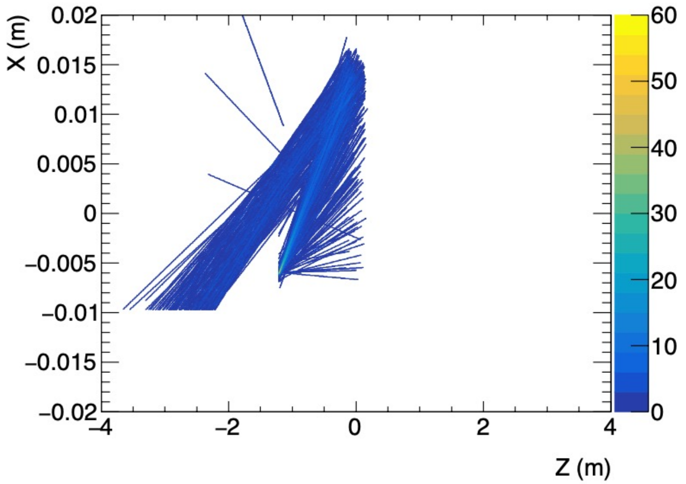
Mitigation – SR Mask

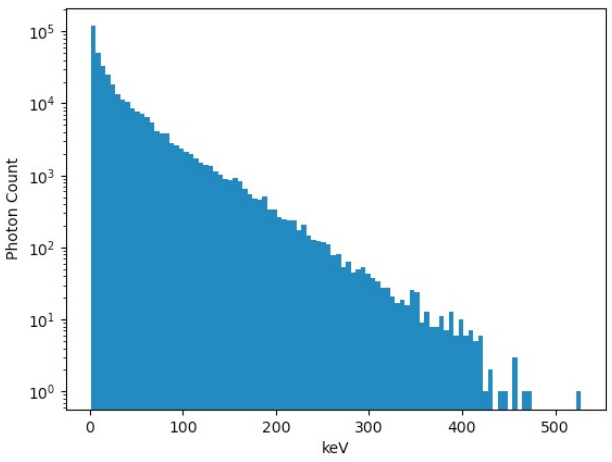
- New mask design:
  - Tungsten
  - 4mm height
  - 10mm long
  - Locates at -1.21m



Mitigation – SR Mask

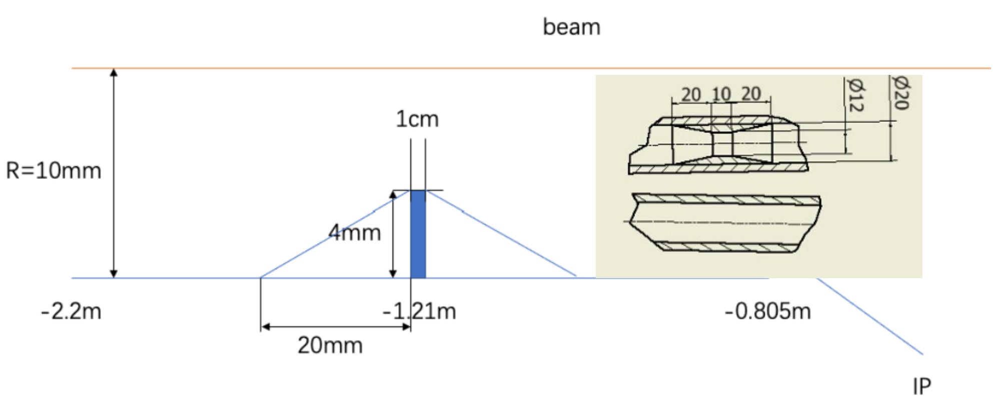


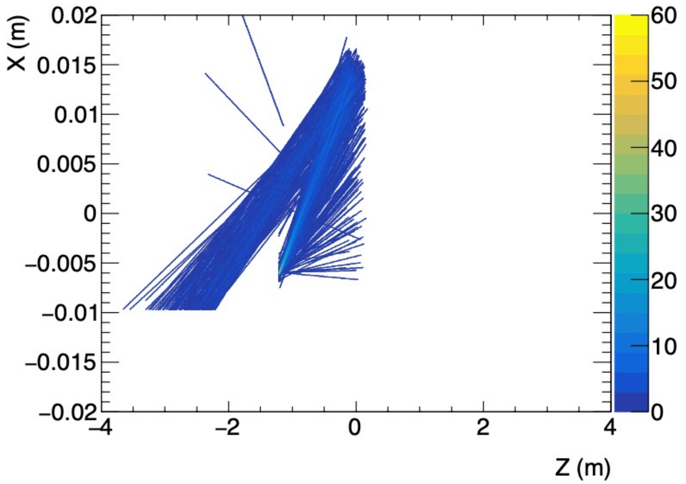


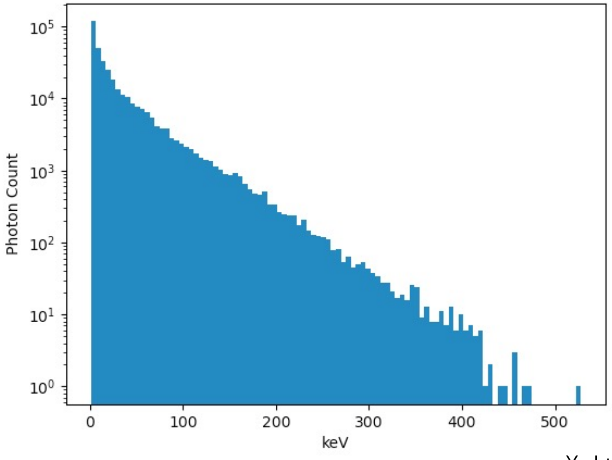


- New mask design:
  - Tungsten
  - 4mm height
  - 10mm long
  - Locates at -1.21m
- Lots of photons are secondaries, generated within QD0
- ~300 photons/BX could hit Be beampipe, with a.e. ~100keV
  - $\sim 1.44\times10^{-8}$ W on Be beampipe

Mitigation – SR Mask

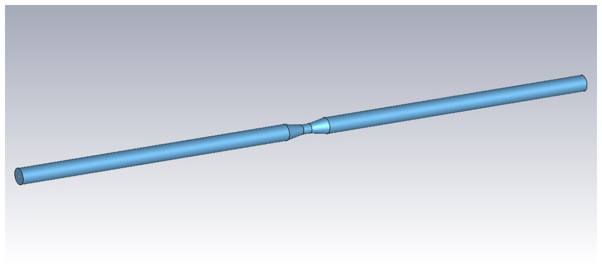


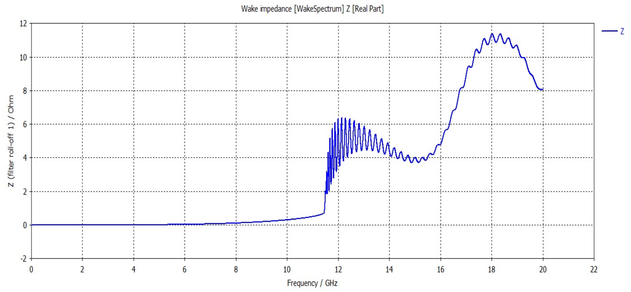




Y. Liu

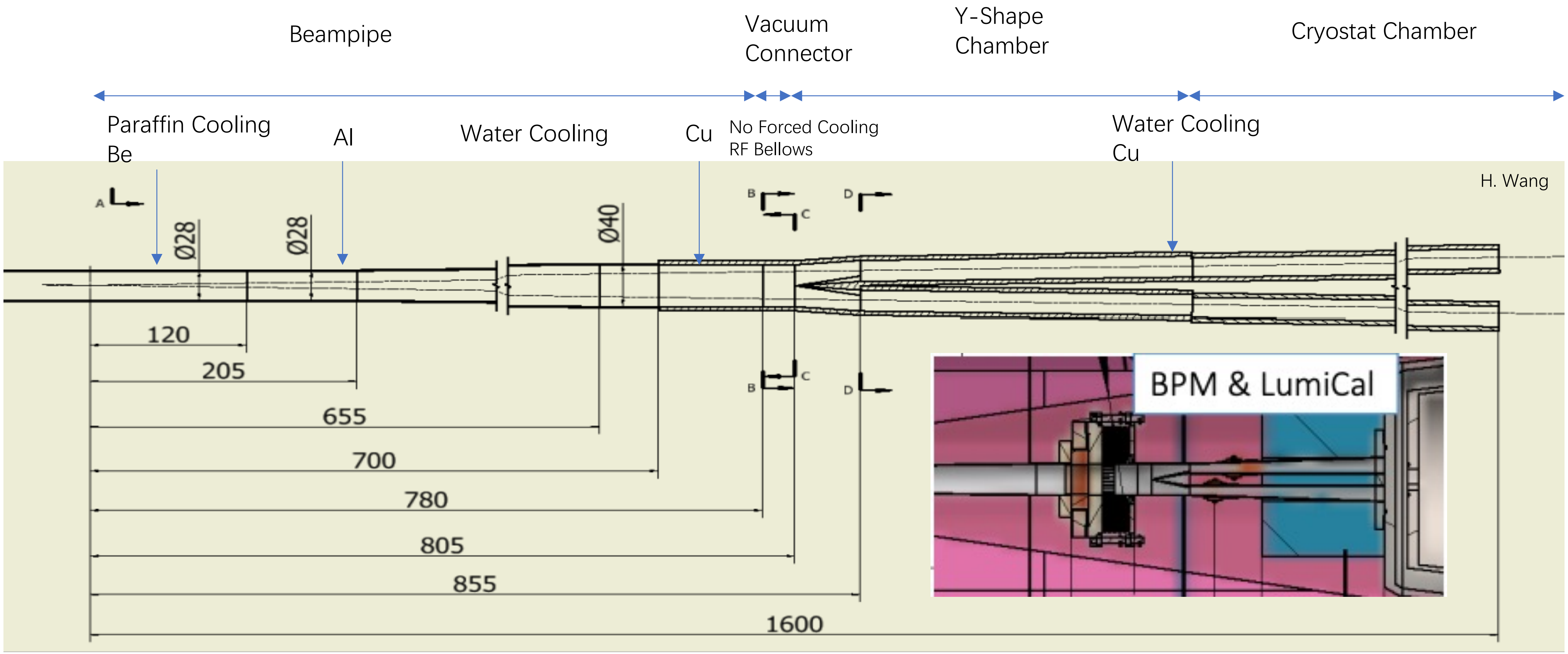
- New mask design:
  - Tungsten
  - 4mm height
  - 10mm long
  - Locates at -1.21m
- Lots of photons are secondaries, generated within QD0
- ~300 photons/BX could hit Be beampipe, with a.e. ~100keV
  - $\sim 1.44\times10^{-8}$ W on Be beampipe





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**

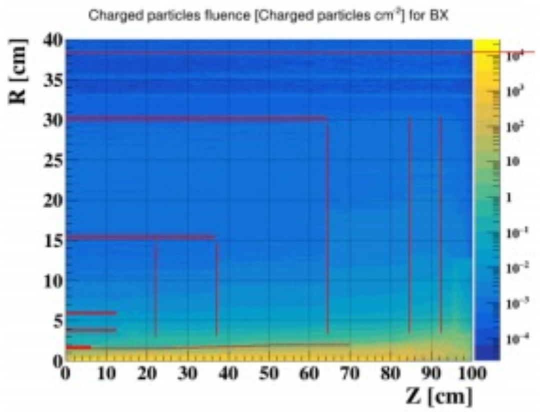
Revised beampipe design

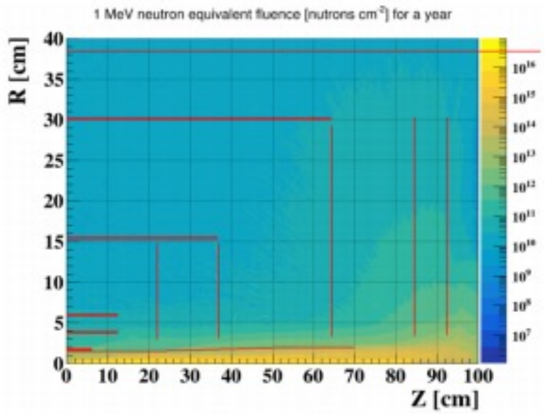


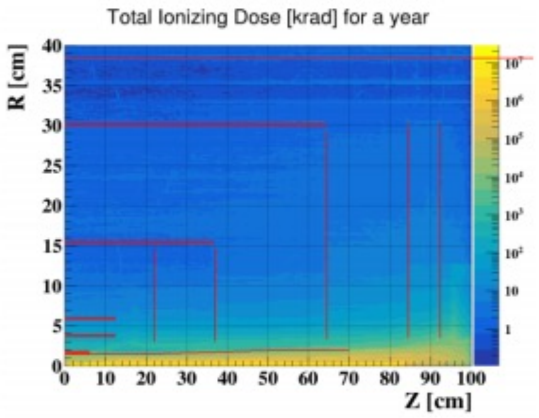
Pair Production

- Detector Impact on 1st layer of vertex detector, with a safety factor of 10

Mode	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)	1 MeV equivalent neutron fluence ($n_{eq} \cdot cm^{-2} \cdot yr^{-1}$)
Higgs	1.81	499.476	$9.68{\times}10^{11}$
W	1.228	8434.486	$1.55{\times}10^{13}$
Z(2T)	0.359	5551.370	$1.06{\times}10^{13}$

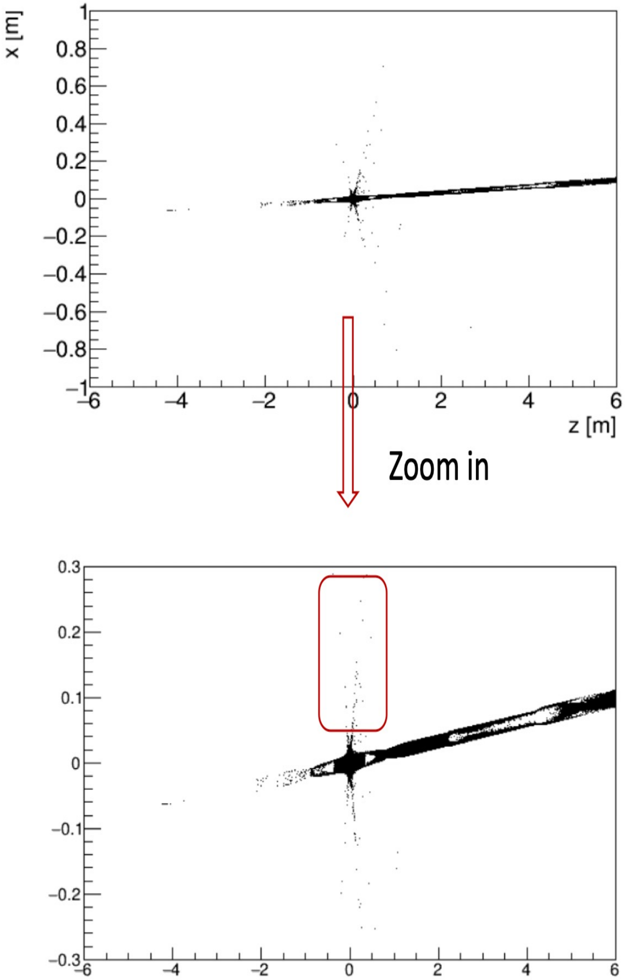






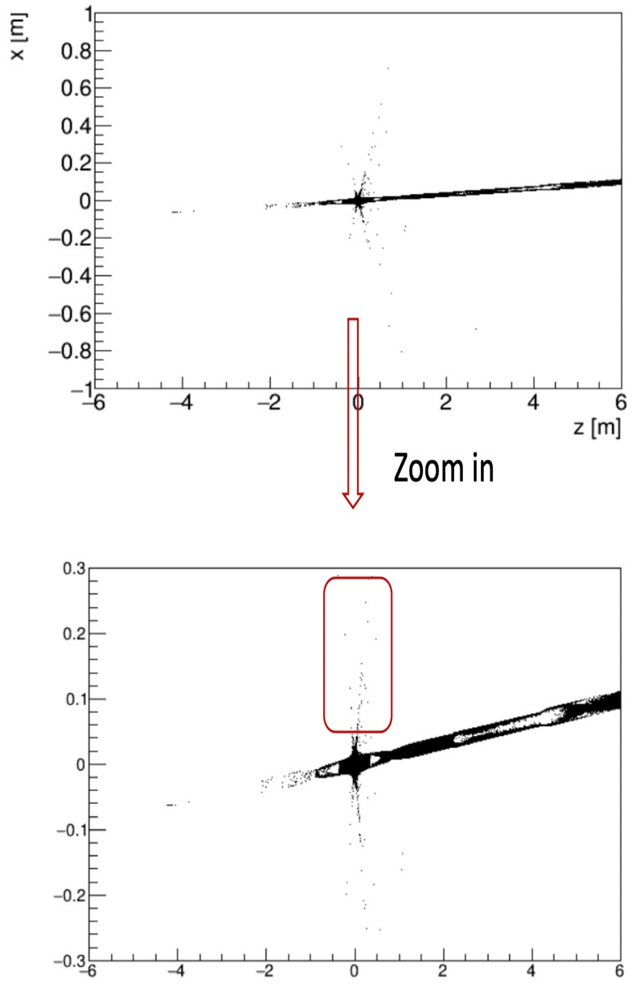
Radiative Bhabha scattering

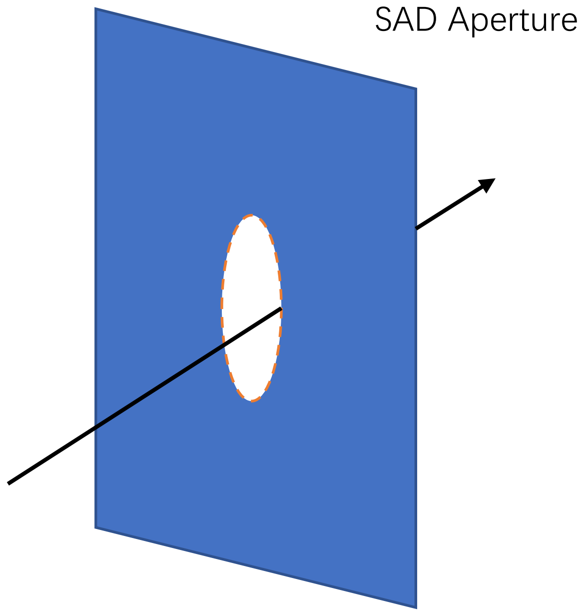
- Lots of loss particles are “outside” of the beampipe.

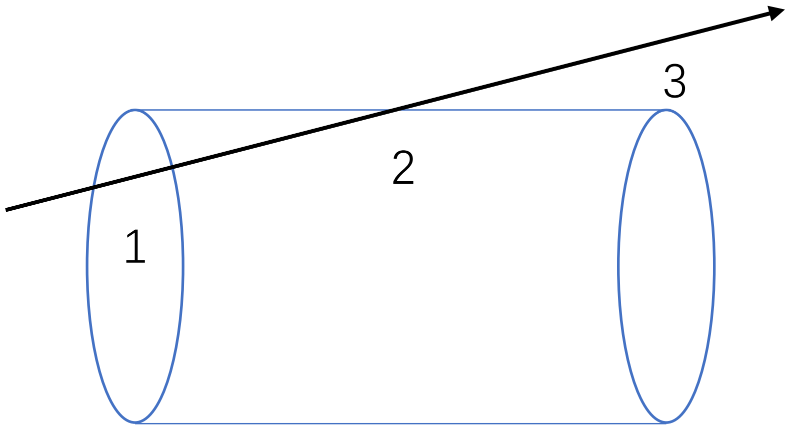


Radiative Bhabha scattering

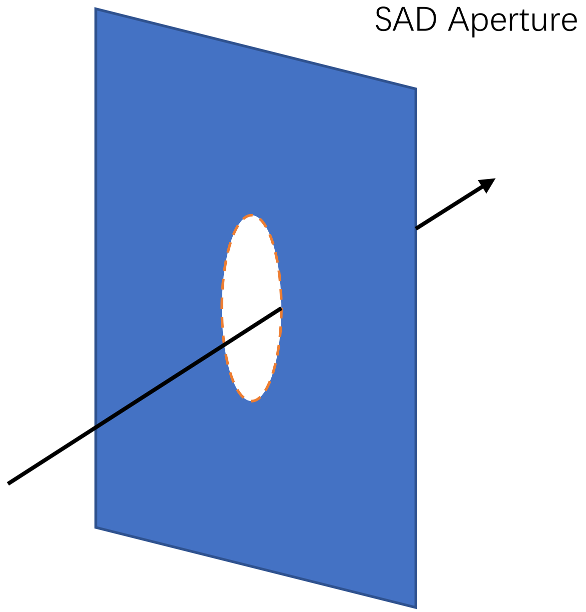
- Lots of loss particles are "outside" of the beampipe.
  - Due to the tracking mechanism of SAD



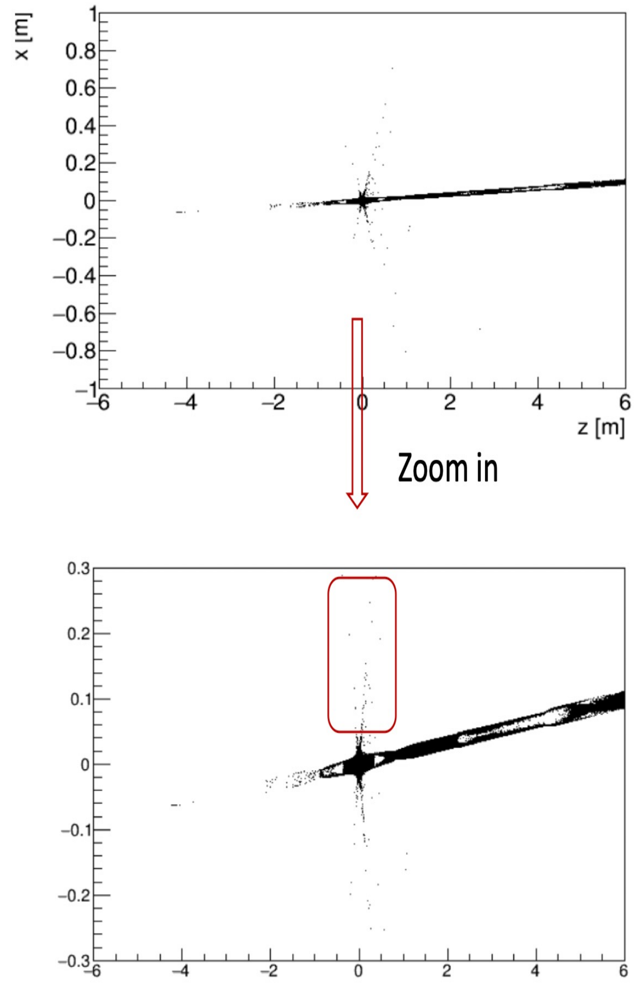


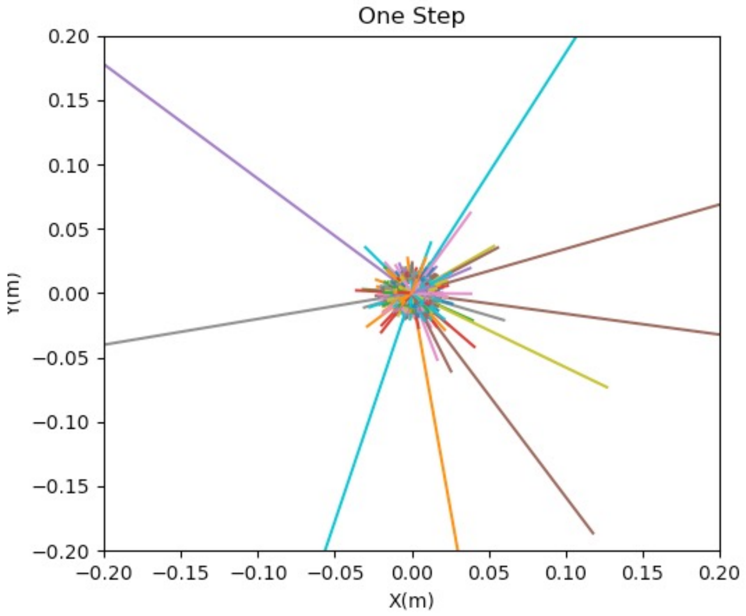


Radiative Bhabha scattering

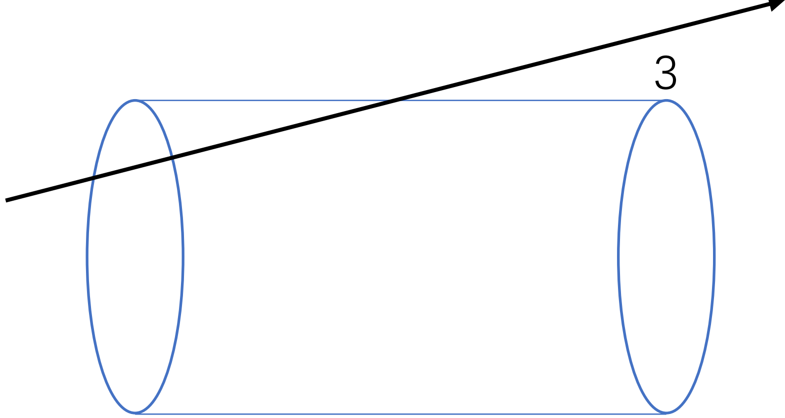


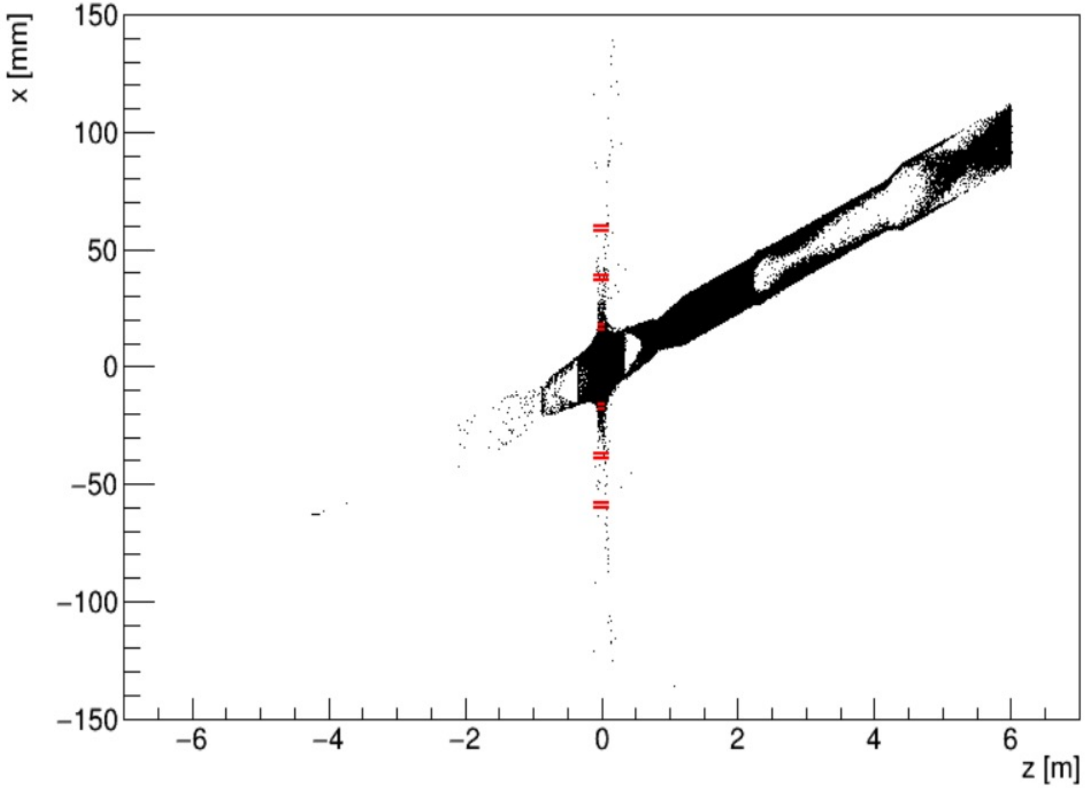
- Lots of loss particles are "outside" of the beampipe.
  - Due to the tracking mechanism of SAD
- The improvement of the tracking method is needed.

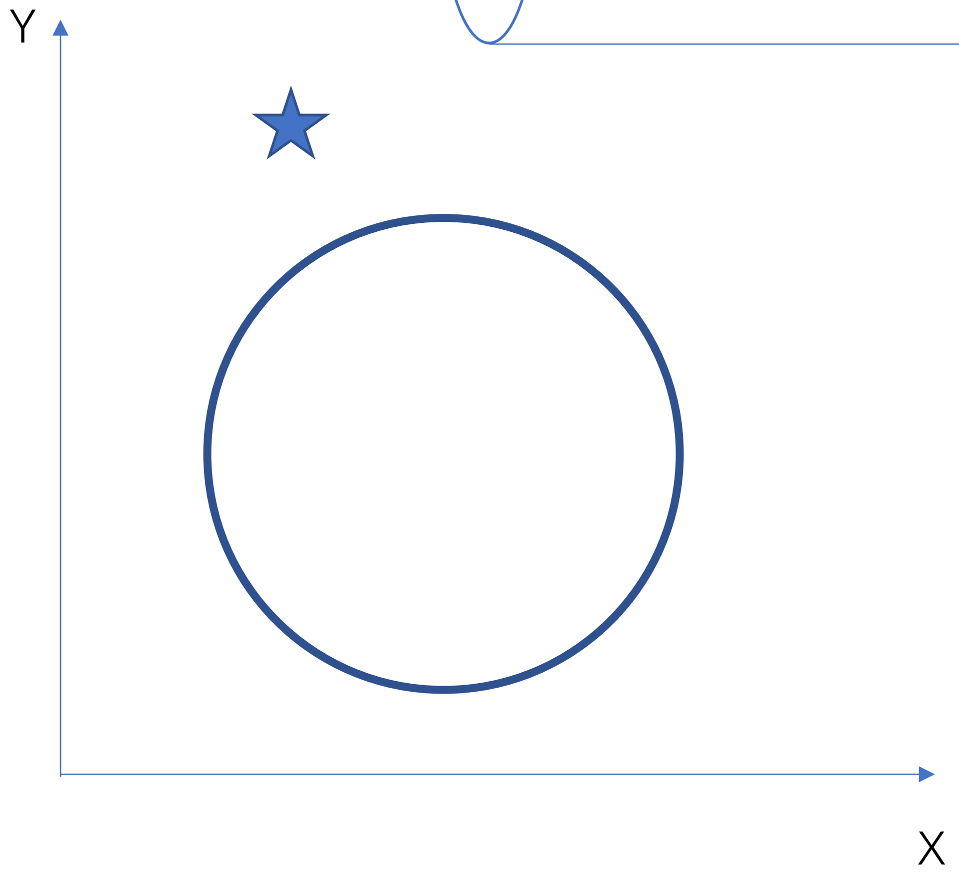




Tracking Method Improvement

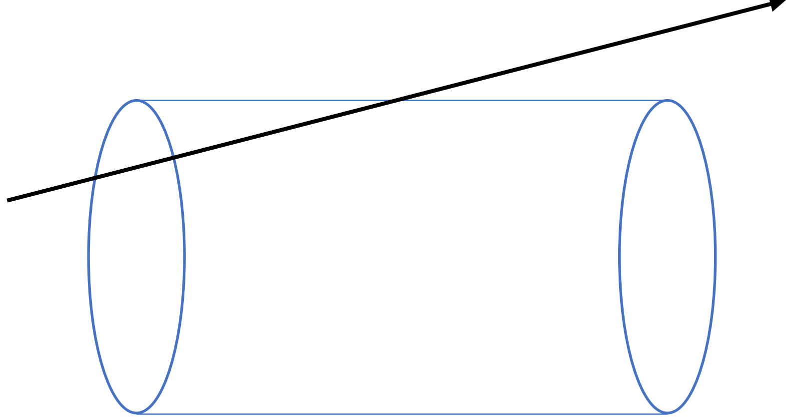


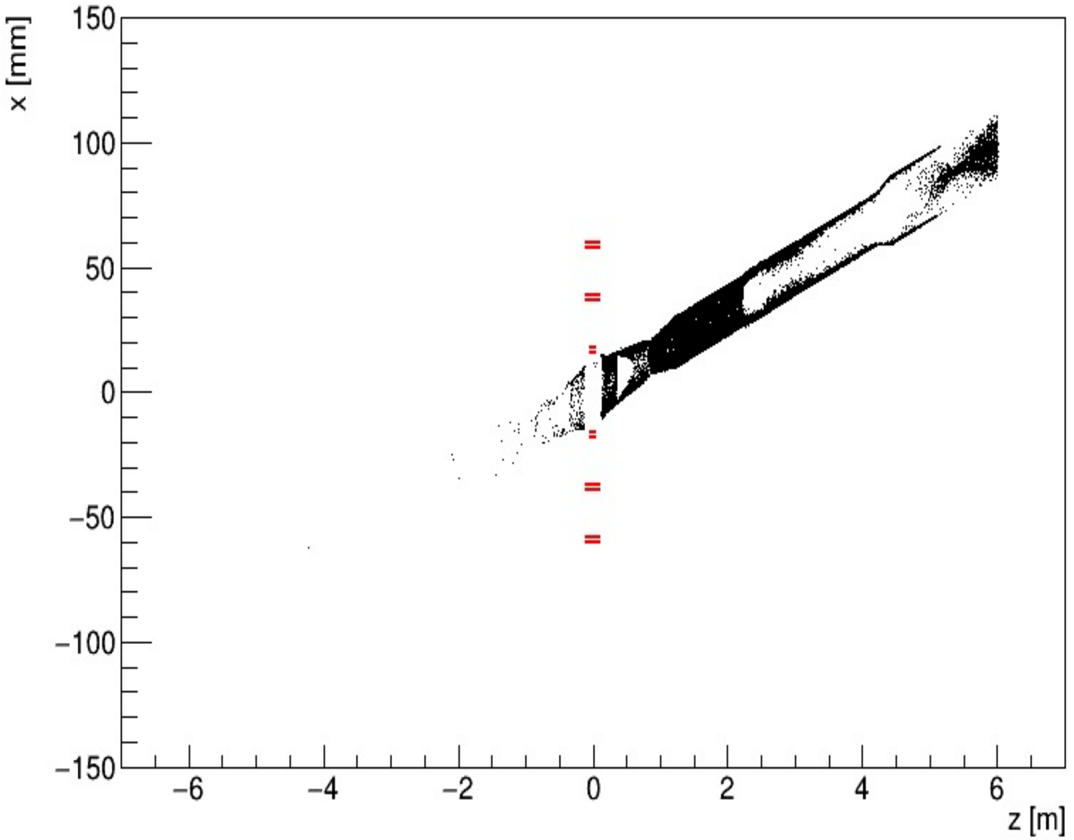


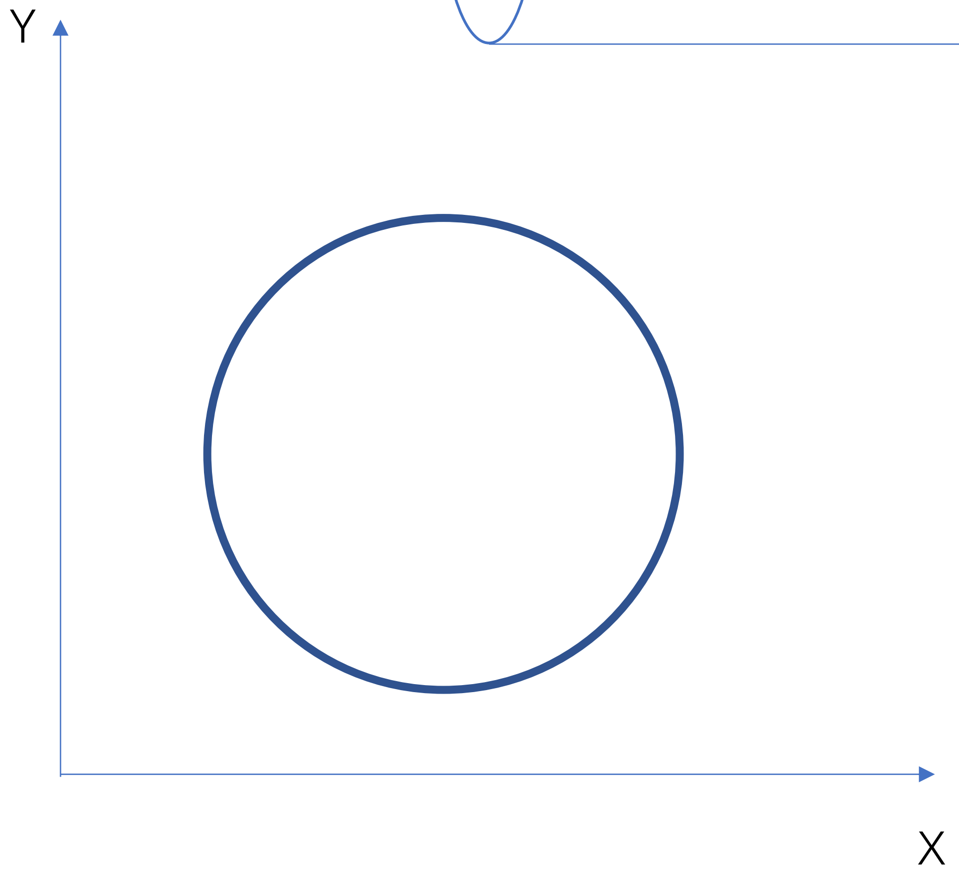


Method 1 – Out

Tracking Method Improvement

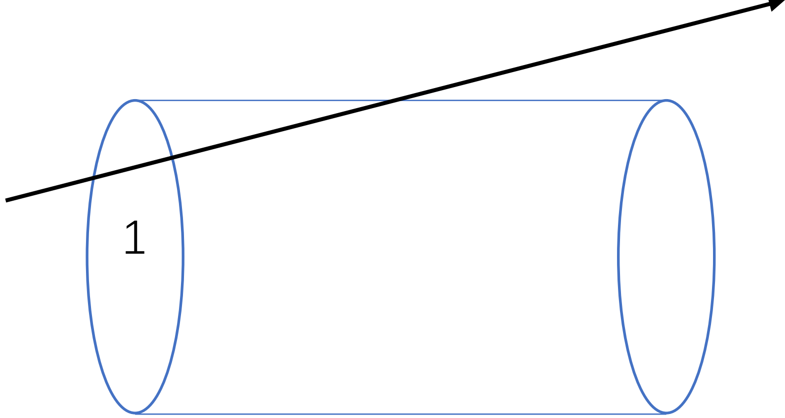


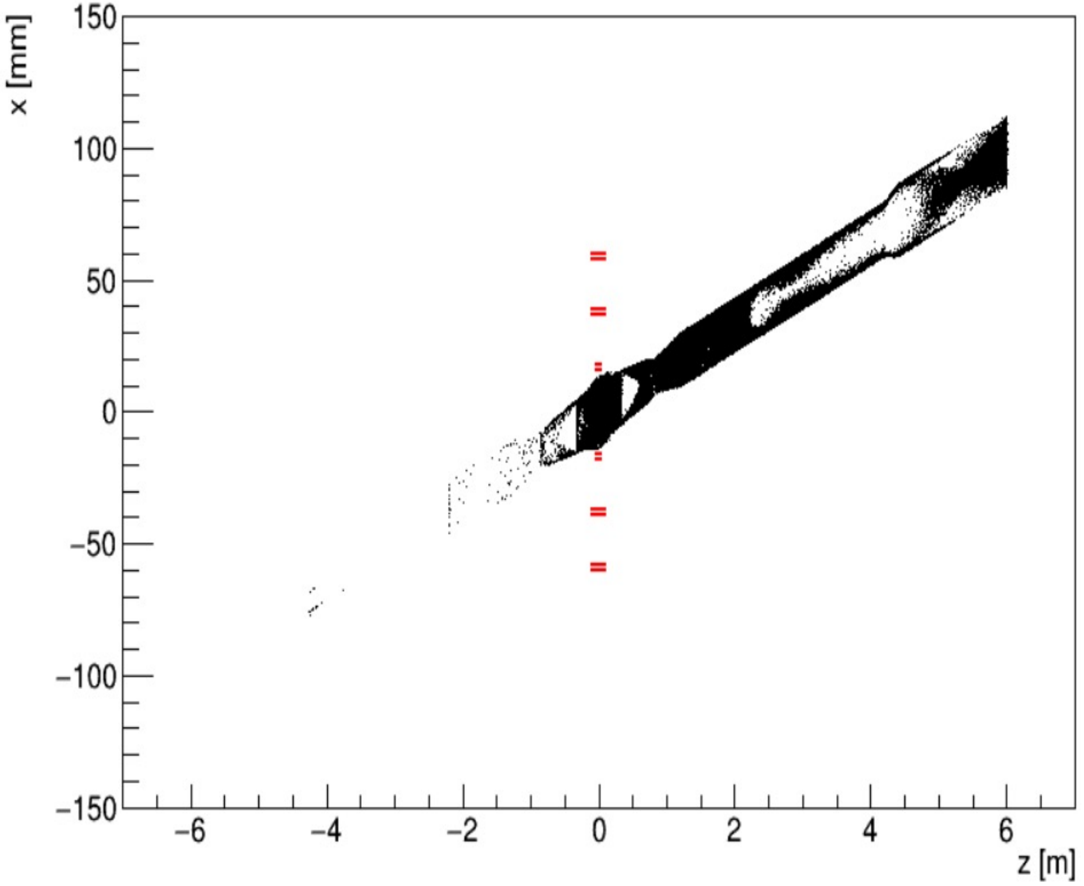


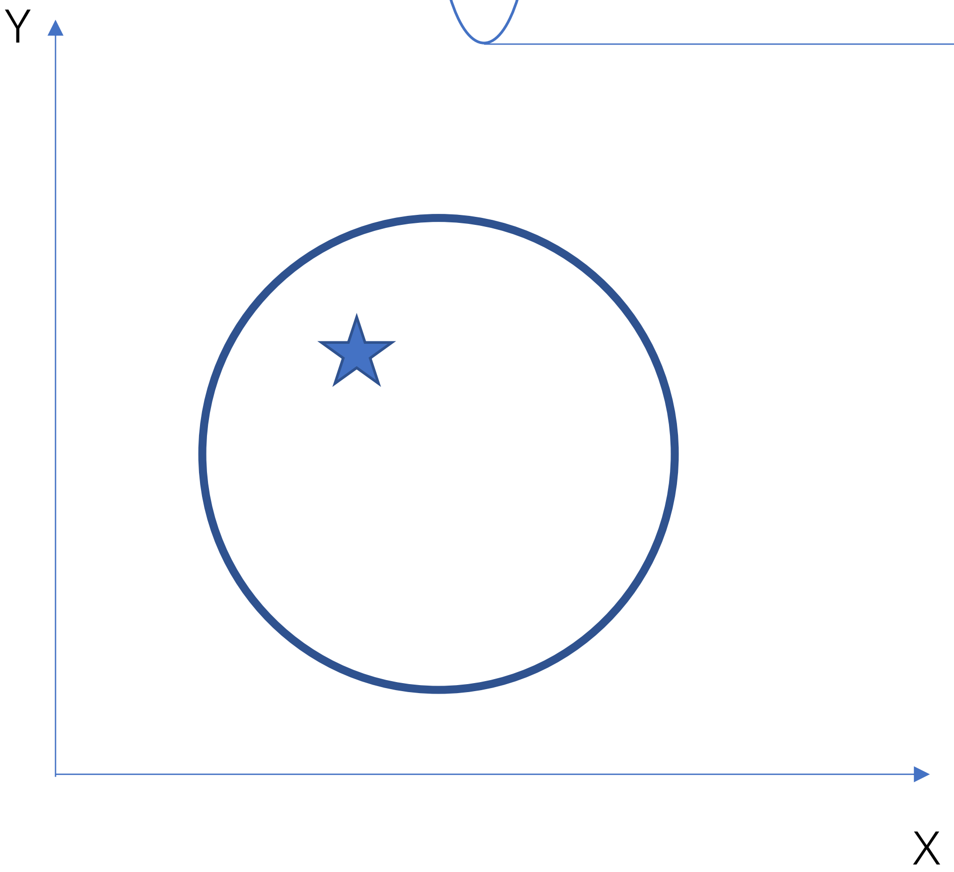


Method 2 – Cut

Tracking Method Improvement

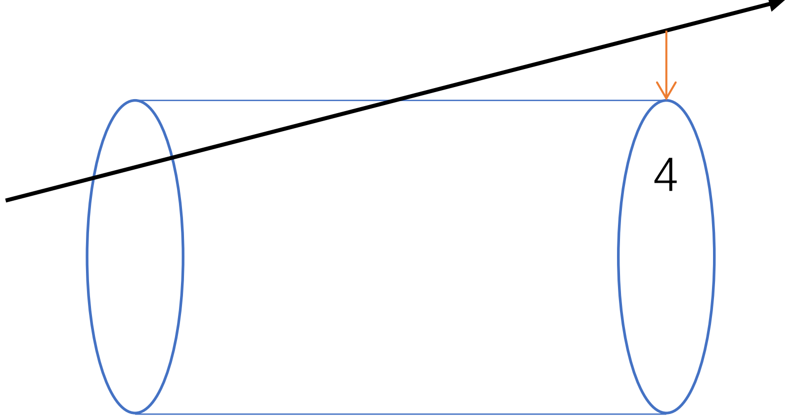


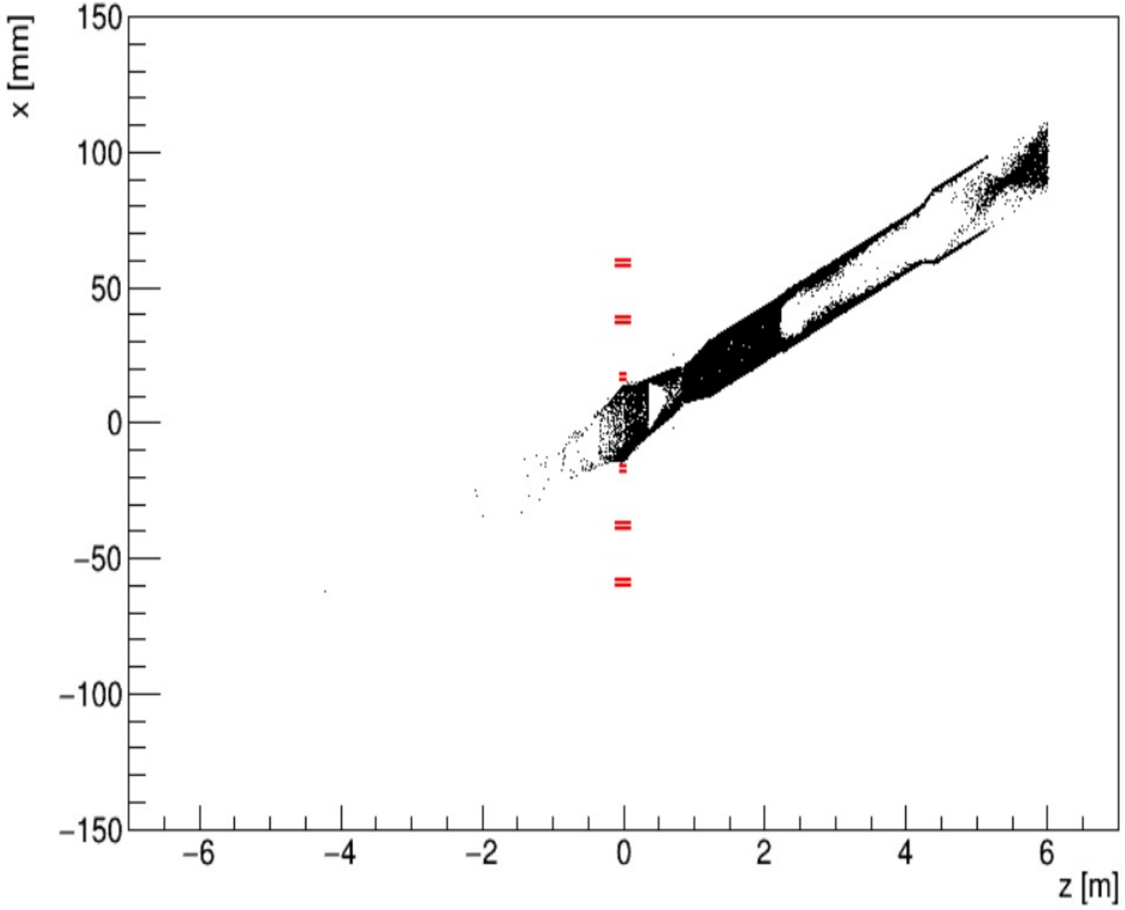


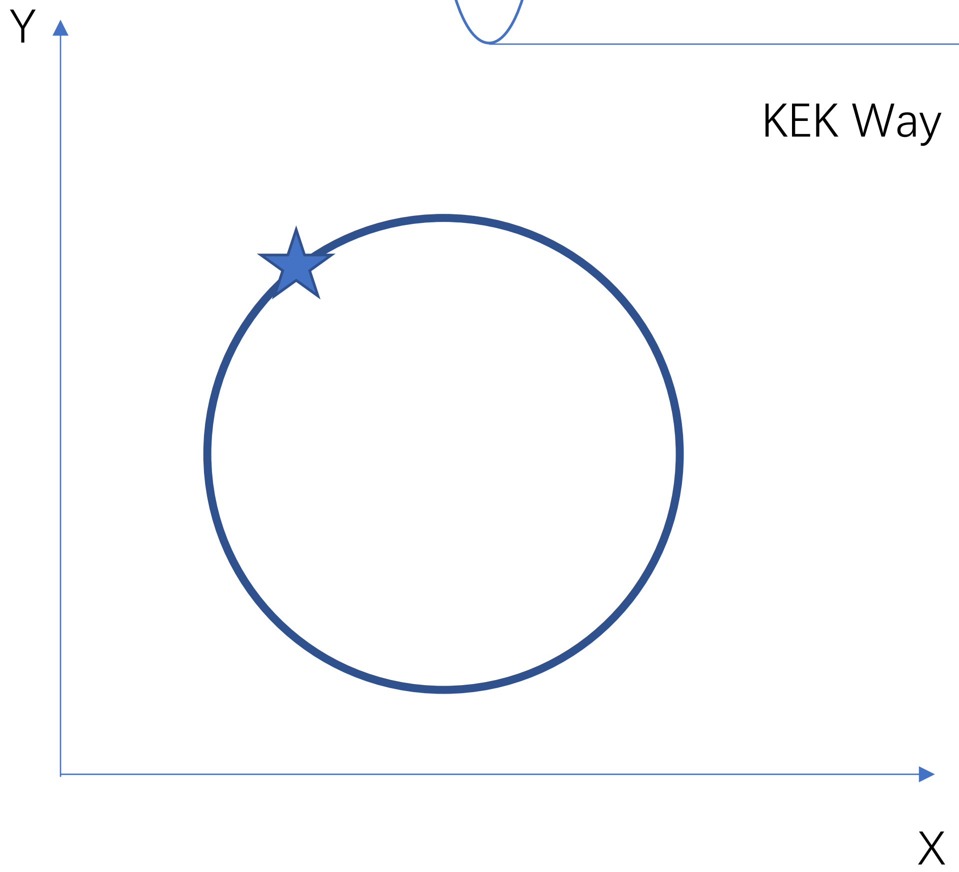


Method 3 – Before

Tracking Method Improvement

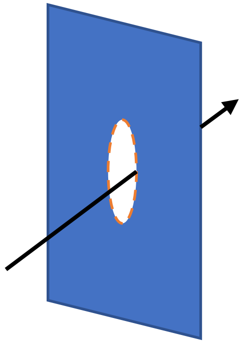


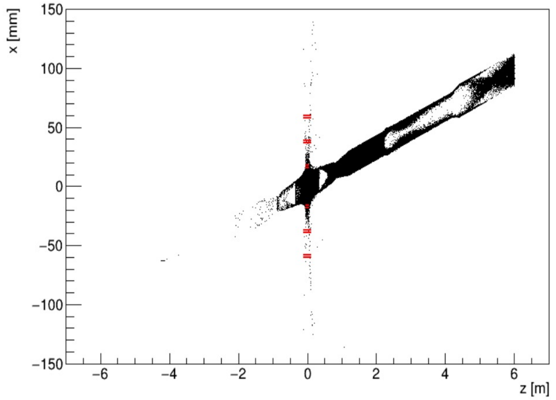




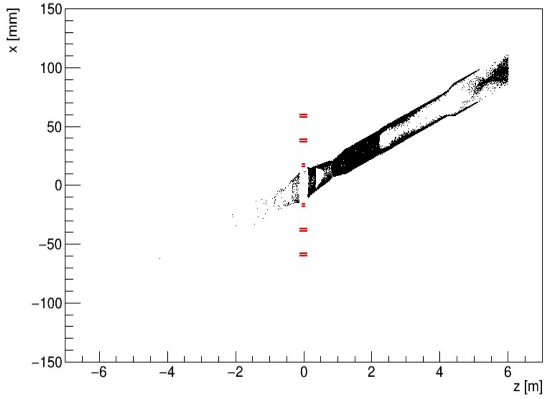
Method 4 – Move

Tracking Method Improvement

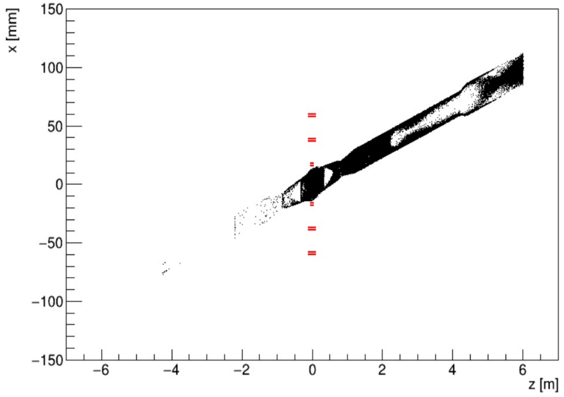




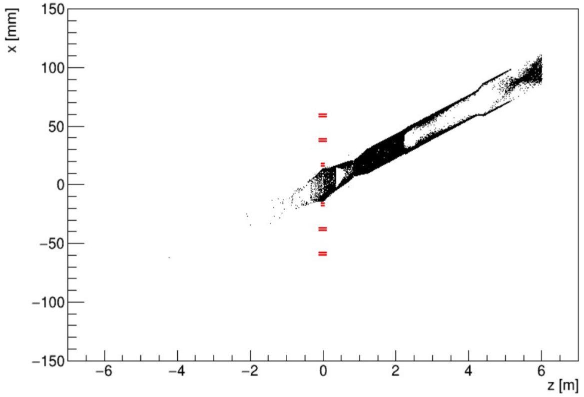
Method 1 – Out



Method 2 – Cut



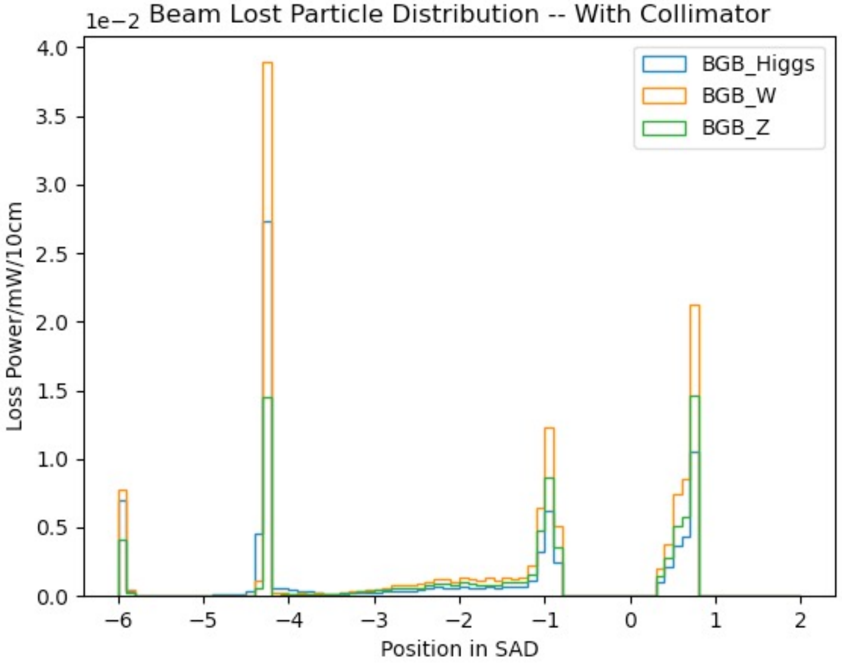
Method 3 – Before



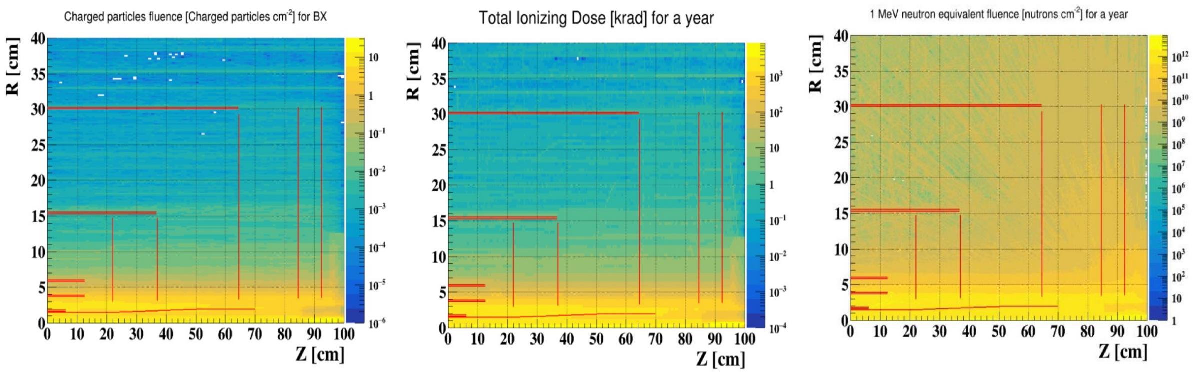
Method 4 – Move

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

Beam Gas Bremsstrahlung



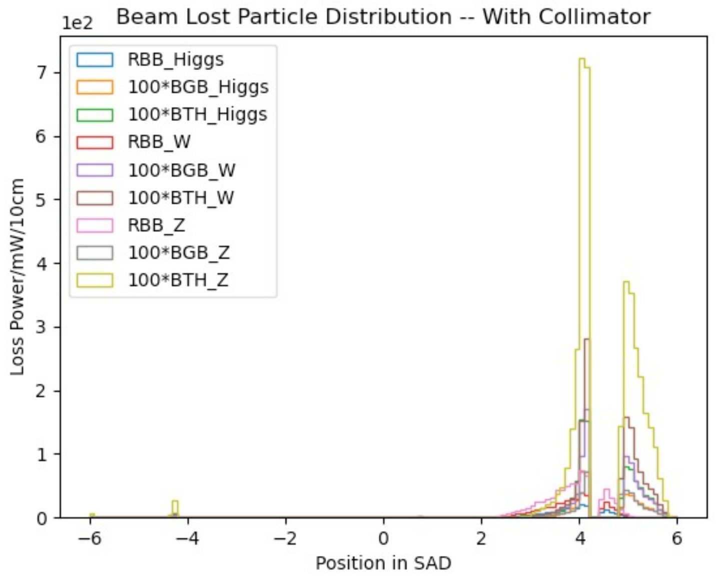
- Updated tracking method applied
  - Method 3(Before)
  - Generate/tracking in whole ring
- Due to tracking method updating, the results decreased from CDR.

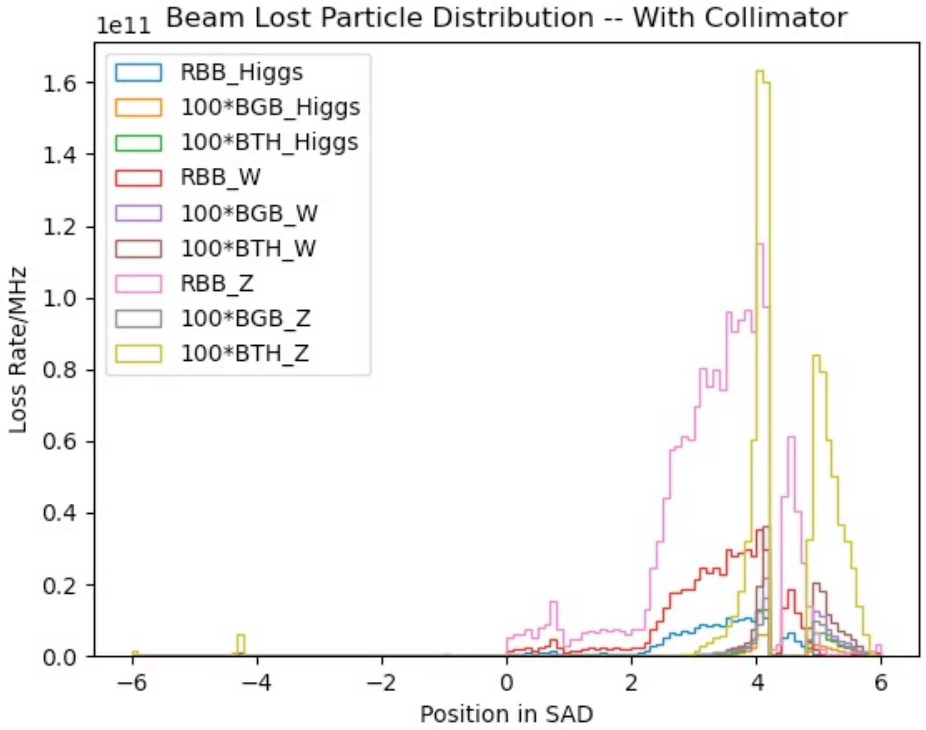


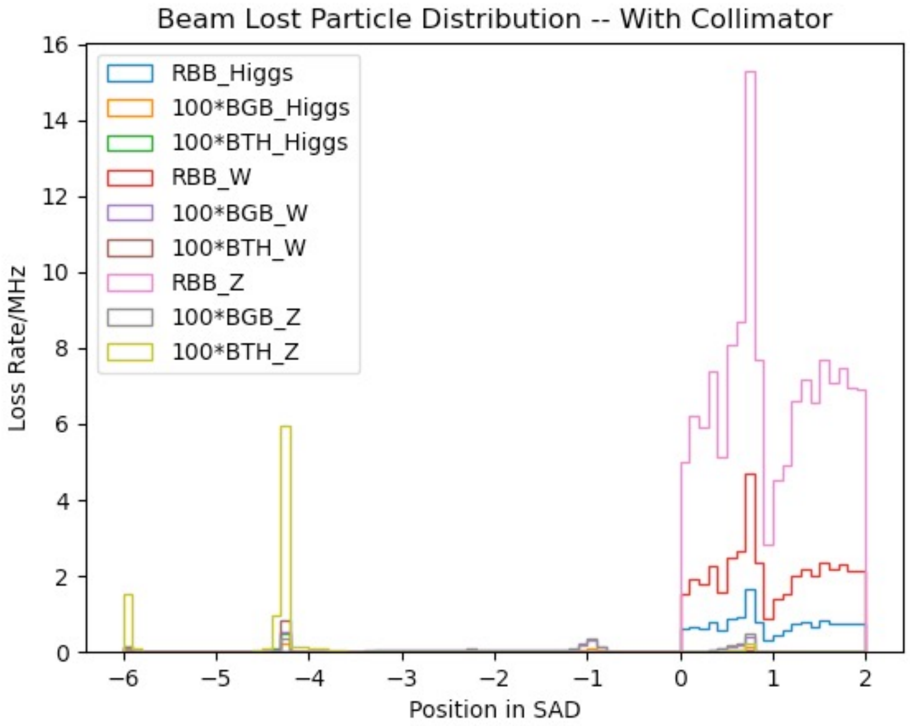
Mode	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)	1 MeV equivalent neutron fluence ($n_{eq} \cdot cm^{-2} \cdot yr^{-1}$)
Higgs	0.359	363.614	9.84×10^{11}
Z(2T)	0.015	225.060	4.18×10^{11}

Lost distribution

- Downstream lost is higher with collimators.
- The lost within downstream magnet is significant.
  - Mitigation and shielding are needed.







Detector Impact

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

Background	Hit Density($cm^{-2} \cdot BX^{-1}$)		TID($krad \cdot yr^{-1}$)		1 MeV equivalent neutron fluence ($n_{eq} \cdot cm^{-2} \cdot yr^{-1}$)	
	Higgs	Z	Higgs	Z	Higgs	Z
Pair production	1.81	0.359	499.476	5551.370	9.68×10^{11}	1.06×10^{13}
Synchrotron Radiation	0.026		15.65			
Radiative Bhabha	0.02		20.3		3.97×10^{10}	
Beam Gas	0.359	2.89×10^{-3}	363.614	181.97	9.84×10^{11}	4.99×10^{11}
Beam Thermal Photon	0.02		22.31		6.20×10^{10}	
Total	2.235		921.35		2.537×10^{12}	

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 – 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
  - $O_{total} = O_{e^+} + O_{e^-} + O_{\mathcal{L}}$
- We hope to perform another run of BG experiment on early April

Summary & Outlook

- We try to finish the work based on CDR
  - 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.
- We plan to benchmark our study with experiments.
  - Using BEPCII/BESIII, hope to be done on early April
- We consider to move to high luminosity design in coming months.

Summary & Outlook

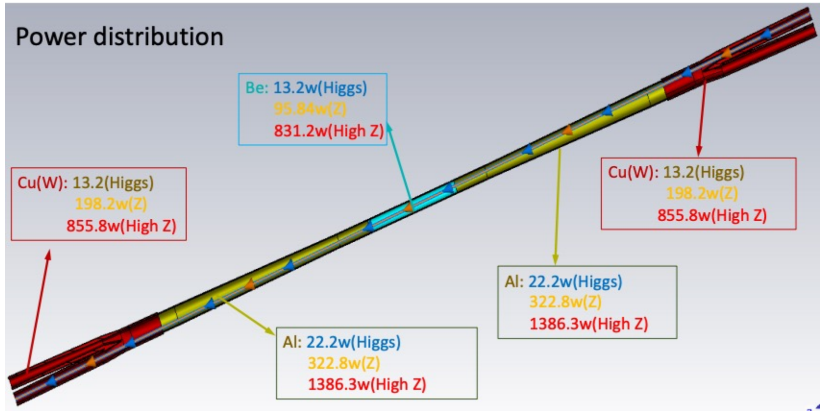
- We try to finish the work based on CDR
  - The finalization of the central beam pipe design has been determined.
  - Mask has been designed, BG simulation and thermal analysis are performed based on new design.
  - Tracking Method has been updated.
- We hope to benchmark our study with experiments.
  - Using BEPCII/BESIII, expect to be done on early April
- We plan to move to high luminosity design in coming months.

Thank You

Backup

HOM analysis for asymmetry

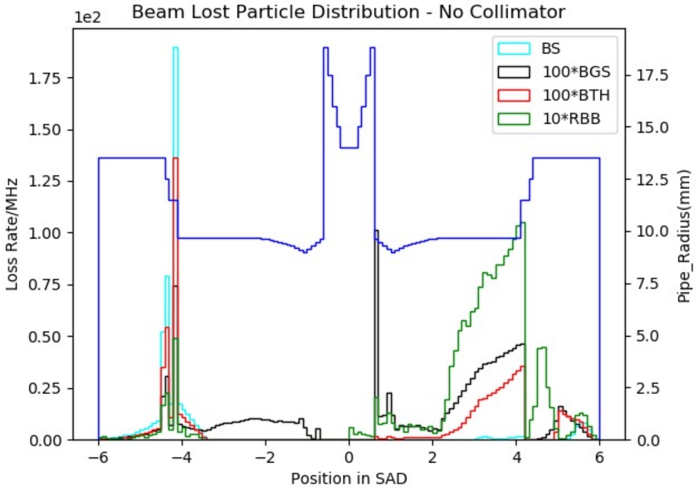
- Maximum HOM Heat load at High-Lumi Z
  - 415.6(Be) + 1386.3(Al) + 855.85 (Cu) W



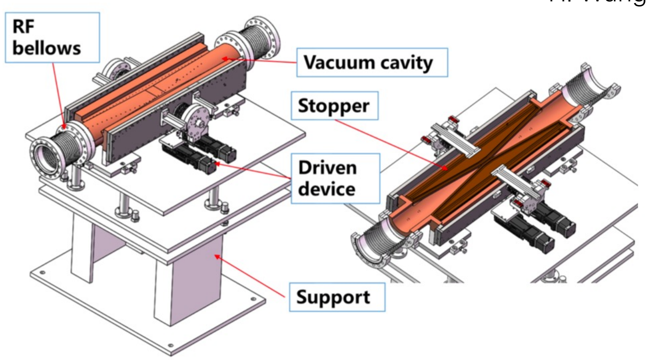
Y. Liu

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

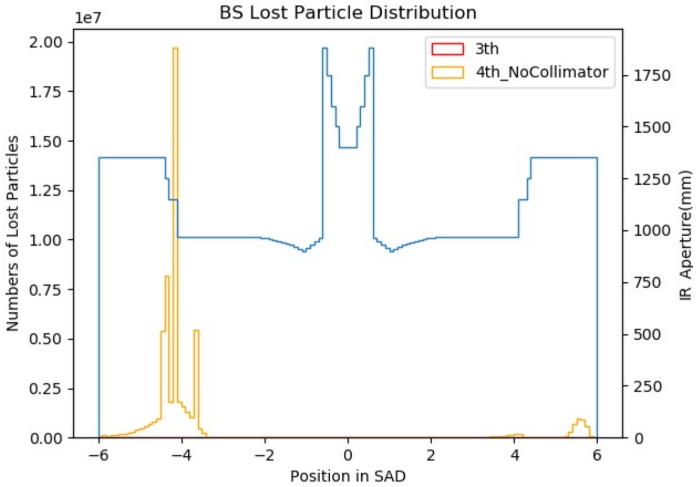
Mitigation – Collimator



H. Wang



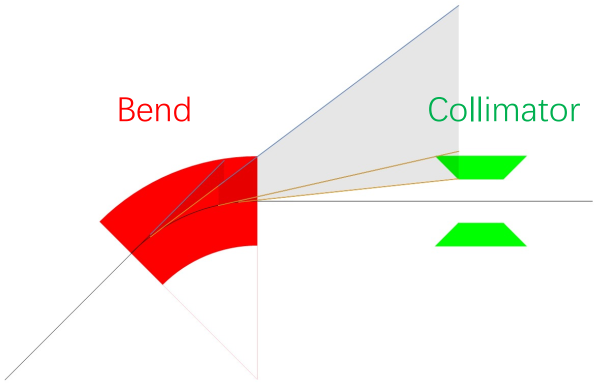
- 2 sets of horizontal collimators have been put in ring.
  - Upstream beam loss have been reduced to low level.
  - We are sure to need more.
- Preliminary design of the movable collimator has been done.
  - Impedance and the SR impact on collimator has been calculated.



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



Combine Results – Original CDR

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}